The impact of tropospheric ozone (O_3) on trees : A meta-analytic review

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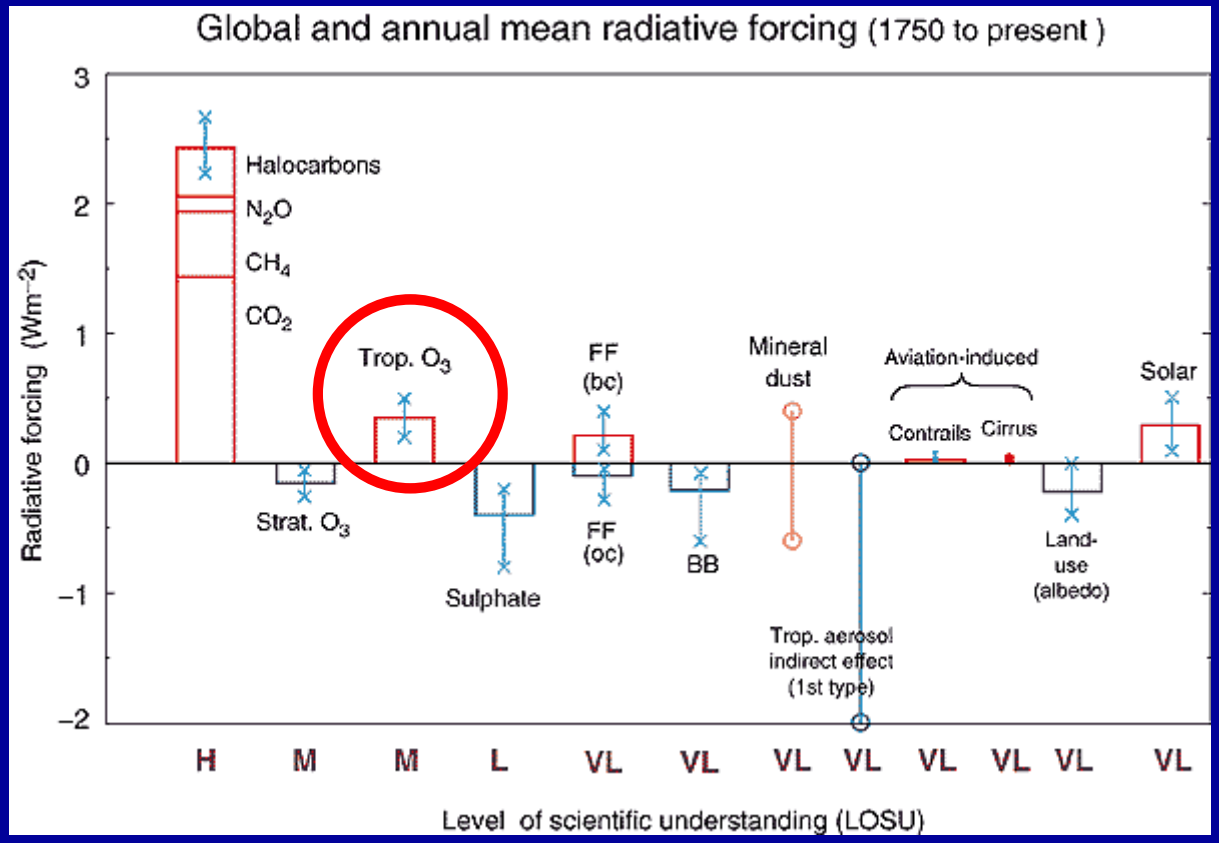
Photo Courtesy of Mihai Aldea


APRIL 3, 2006
www.time.com AOL Keyword: TIME
SPECIAL REPORT GLOBAL WARMING
TIME
BE WORRIED. BE VERY WORRIED.
Climate change isn't some vague future problem—it's already damaging the planet at an alarming pace. Here's how it affects you, your kids and their kids as well
EARTH AT THE TIPPING POINT
HOW IT THREATENS YOUR HEALTH
HOW CHINA & INDIA CAN HELP SAVE THE WORLD—OR DESTROY IT
THE CLIMATE CRUSADERS

Ozone is a Greenhouse Gas with the 3rd Largest Radiative Forcing



Intergovernmental Panel on Climate Change Third Assessment Report (IPCC-TAR; 2001), *Climate Change 2001: The Scientific Basis*

Air Quality Awareness Week - Microsoft Internet Explorer

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Address http://www.epa.gov/airnow/airaware/airaware.html

Air Quality Awareness Week

The U.S. Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration's (NOAA) National Weather Service urge Americans to "Be Air Aware" during Air Quality Awareness Week, May 15 - 19, 2006. See state and local Air Quality Awareness Week activities.

Monday, May 15: Ozone and Particle Pollution

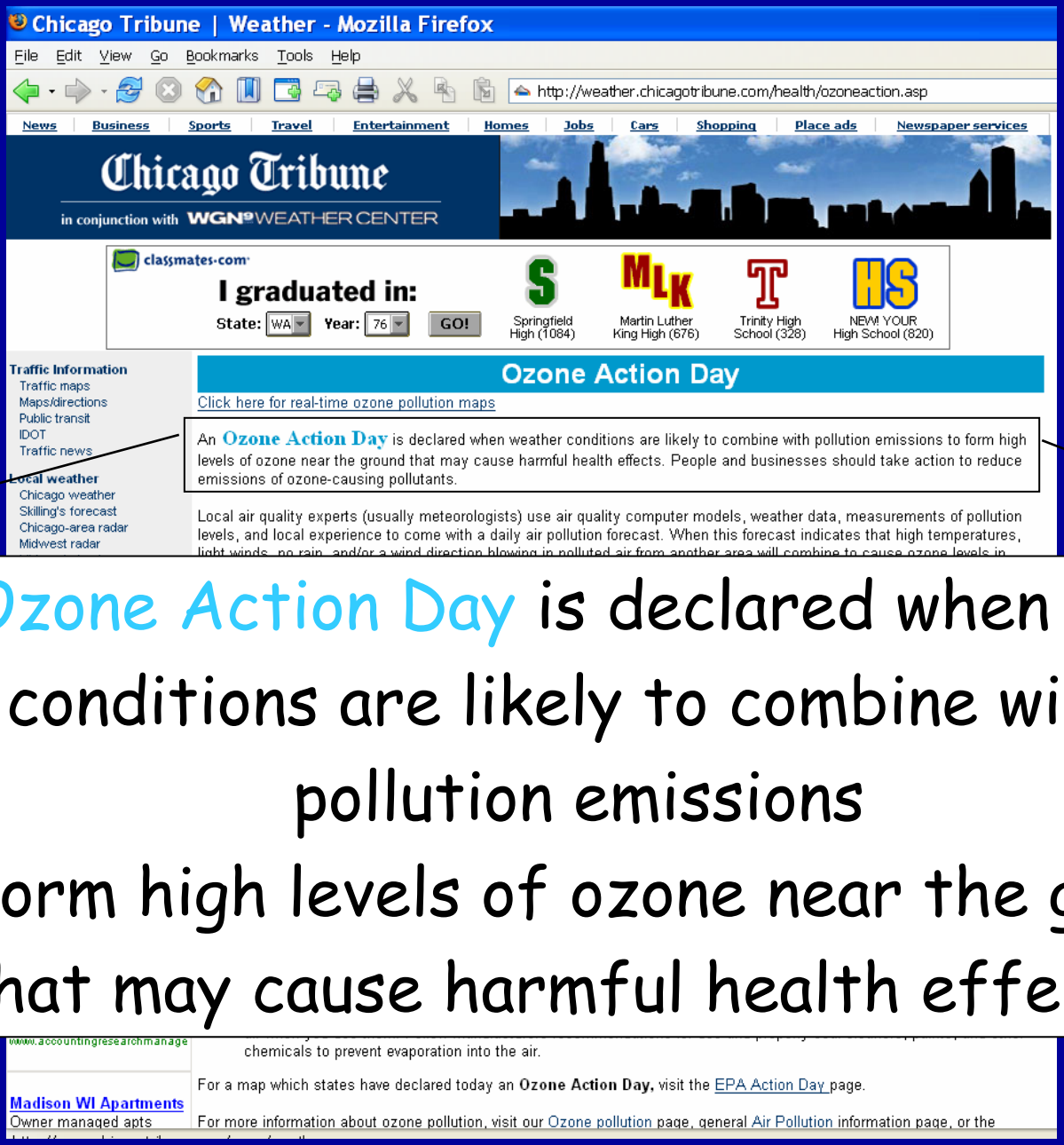
- What is Air Pollution?
- What is Ozone?
- What is Particle Pollution?

Tuesday, May 16: What Causes Poor Air Quality

- What Affects my Air Quality?
- It All Adds Up To Cleaner Air - spring quiz

Wednesday, May 17: Keeping Your Lungs and Heart Safe

- Keeping Your Lungs and Heart Safe:
  Use the Air Quality Index to Protect Against Poor Air Quality
- Forecast Earth "Air Aware" Video
- Asthma Awareness Month



"An Ozone Action Day is declared when weather conditions are likely to combine with pollution emissions to form high levels of ozone near the ground that may cause harmful health effects."

USATODAY.com - Checking ozone levels becoming routine for many

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08/20/2001 - U

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By Patrick

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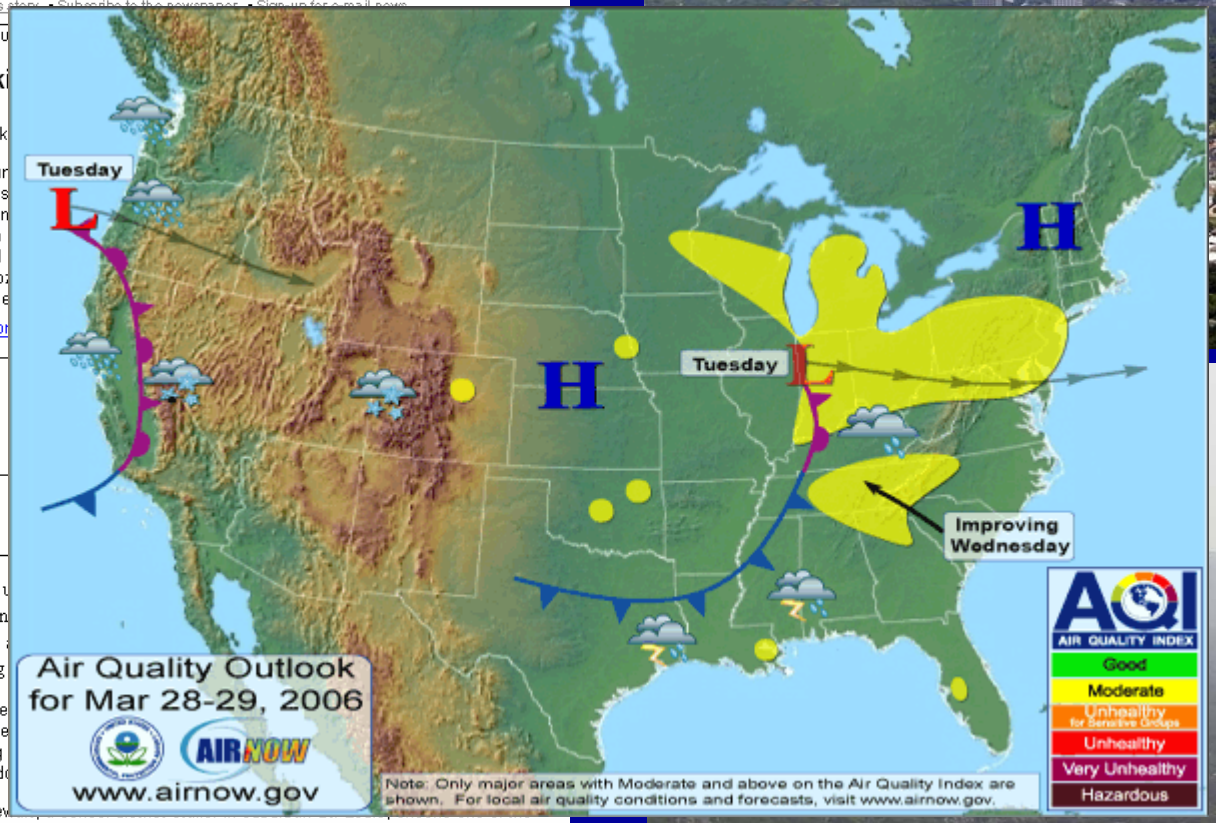
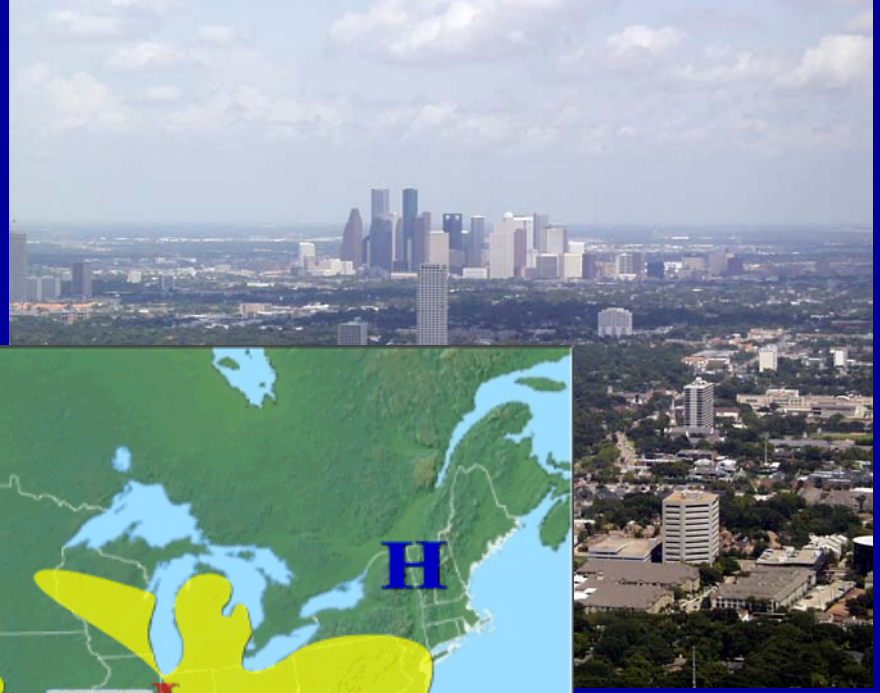
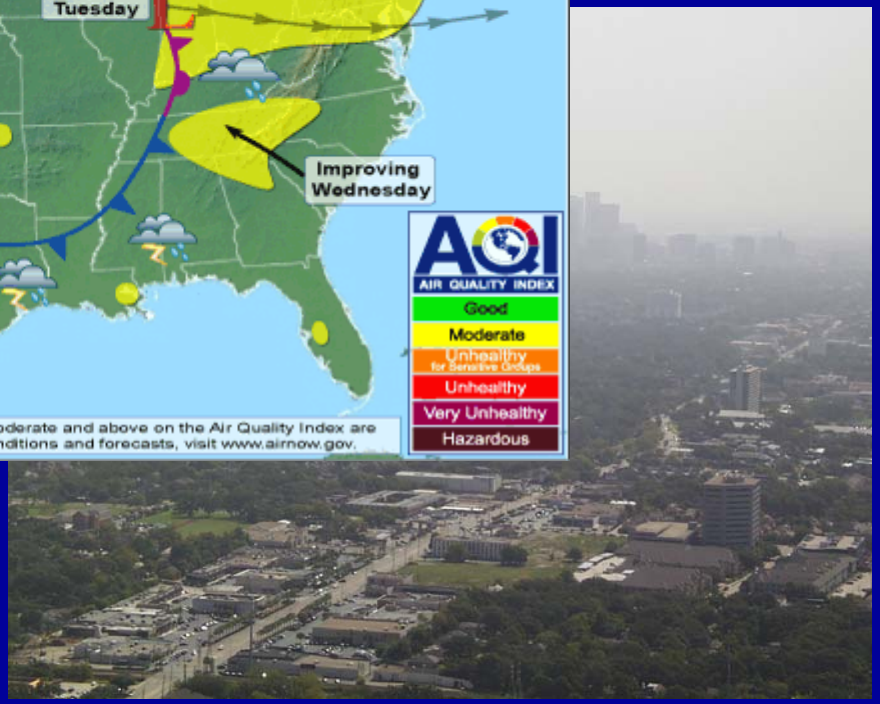
Diana Stew
Missouri Department of Transportation's message boards that flash the next day's ozone forecast along busy commuter routes. "I find myself looking for it," says Stewart, a jogger who also gets e-mail alerts. "Is it going to be a 'green' day tomorrow, or a 'yellow' day or a 'red' day? Sucking bad air will scare me away from running, even in the early morning."

In Chapel Hill, N.C., artist Helen Davis catches the air outlook on her public radio station's morning newscast. "I'm not alarmist about it," she says, "but I think about it. This is the first place I've lived that I was so aware of it."

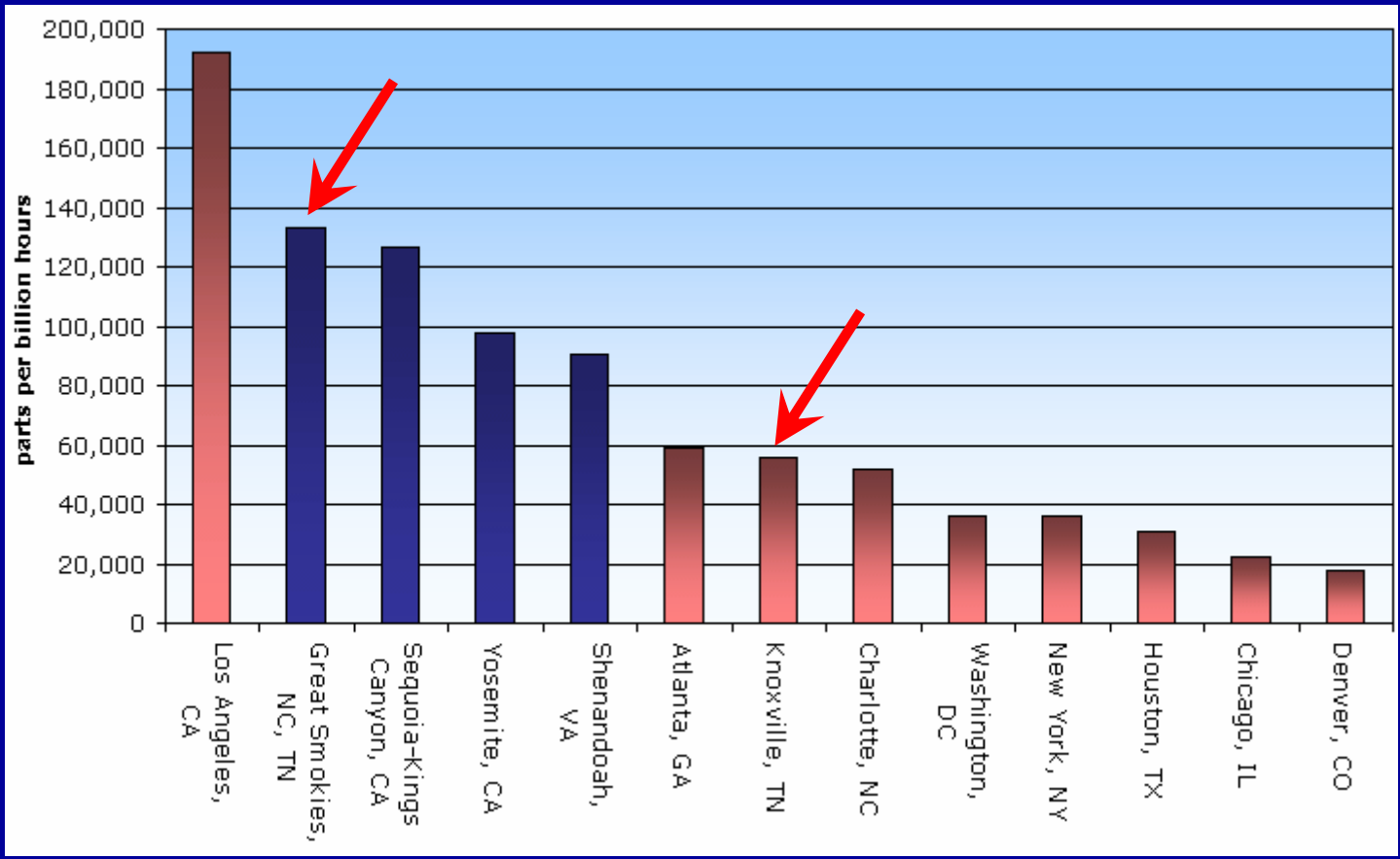
Transferring data from www.usatoday.com...





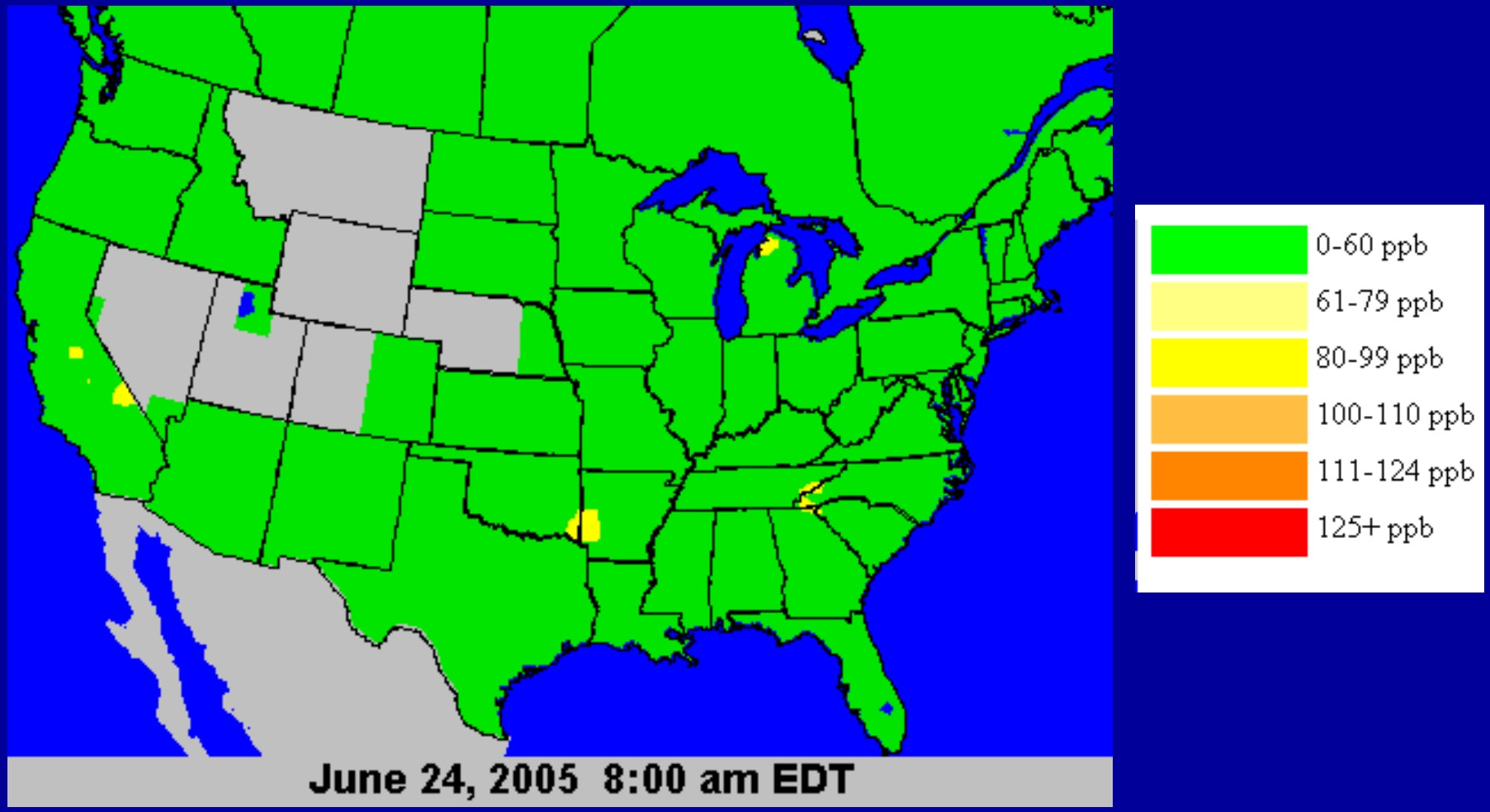


Ozone doses between 1991-2001 in major cities and four major national parks



from National Park Conservation Association: www.npca.org

Urban Myth-Busted: Not just a problem of big cities!



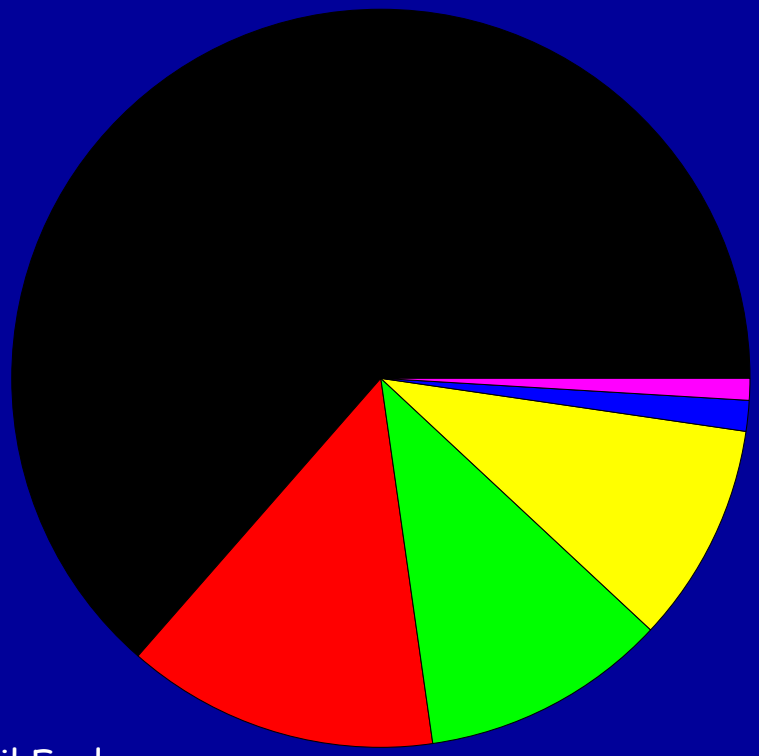
http://www.airnow.gov

Look Rock, Great Smoky Mountain National Park, June 24, 2005 2:00 pm

Sunlight + NO_x + VOCs → O_3

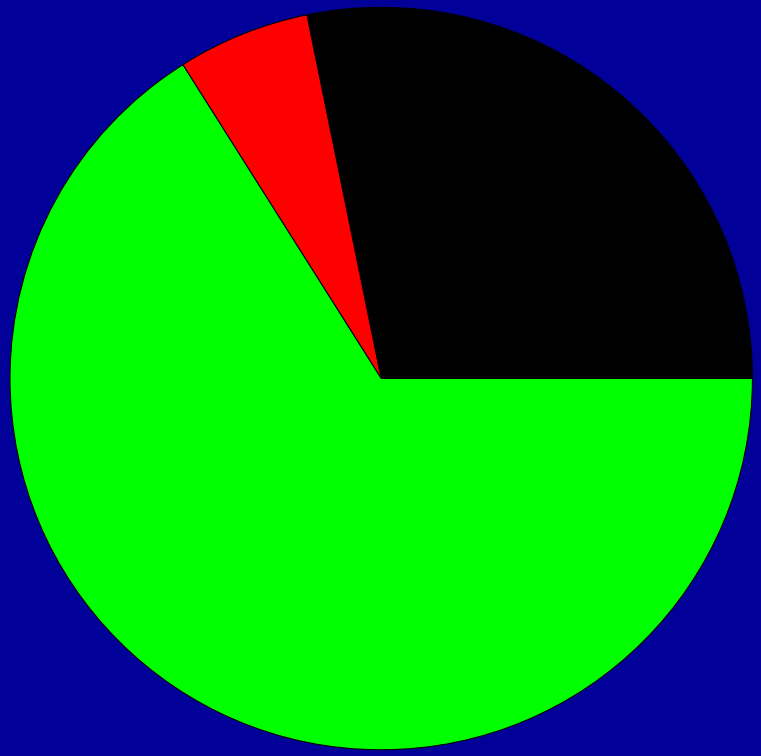
Sources of O_3 Precursor Emissions (%)

NOx



Fossil Fuels
Biomass Burning
Soils
Lightning
Aircraft
Stratosphere

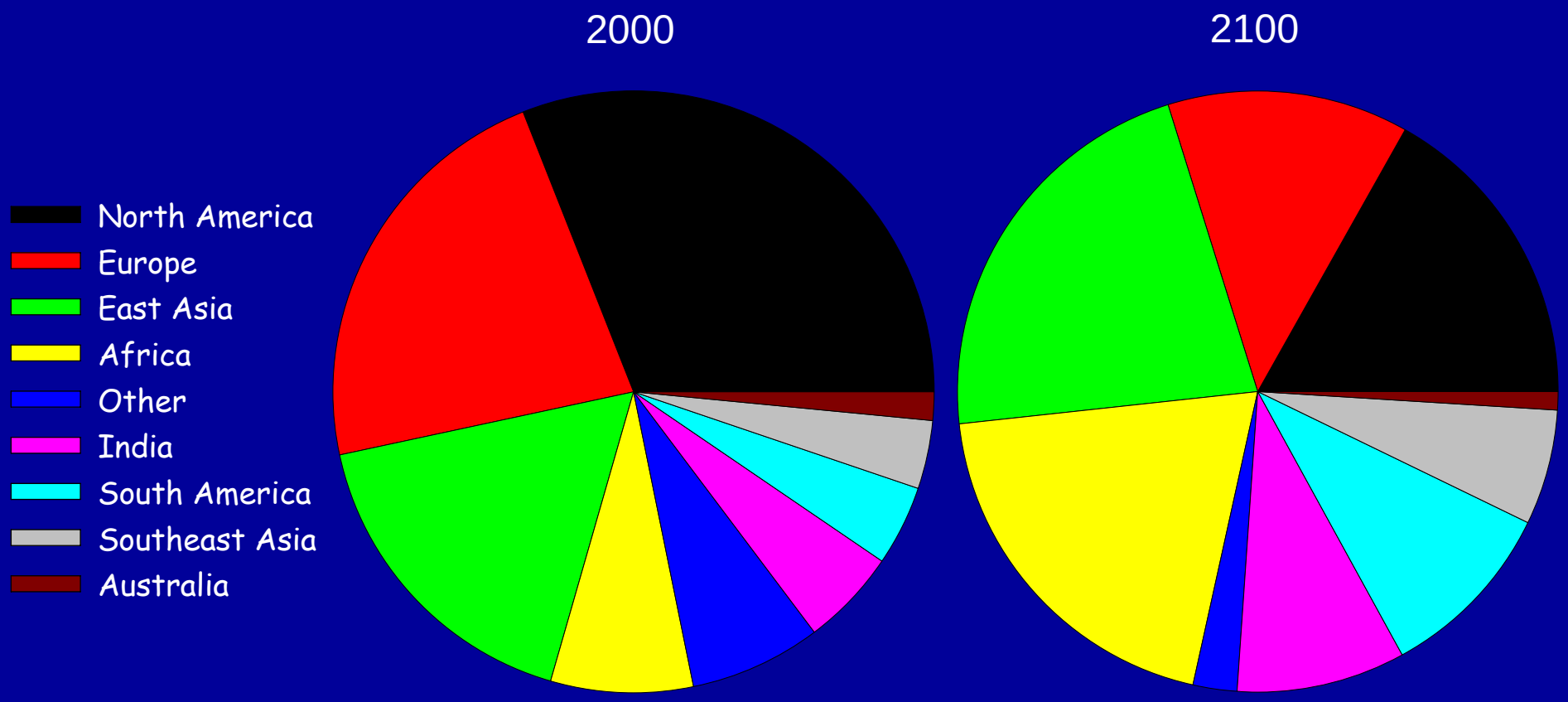
VOCs



Fossil Fuel
Biomass Burning
Vegetation

IPCC-TAR (2001), *Climate Change 2001: The Scientific Basis*

Anthropogenic Emissions of NOx (%) by Continent/Region



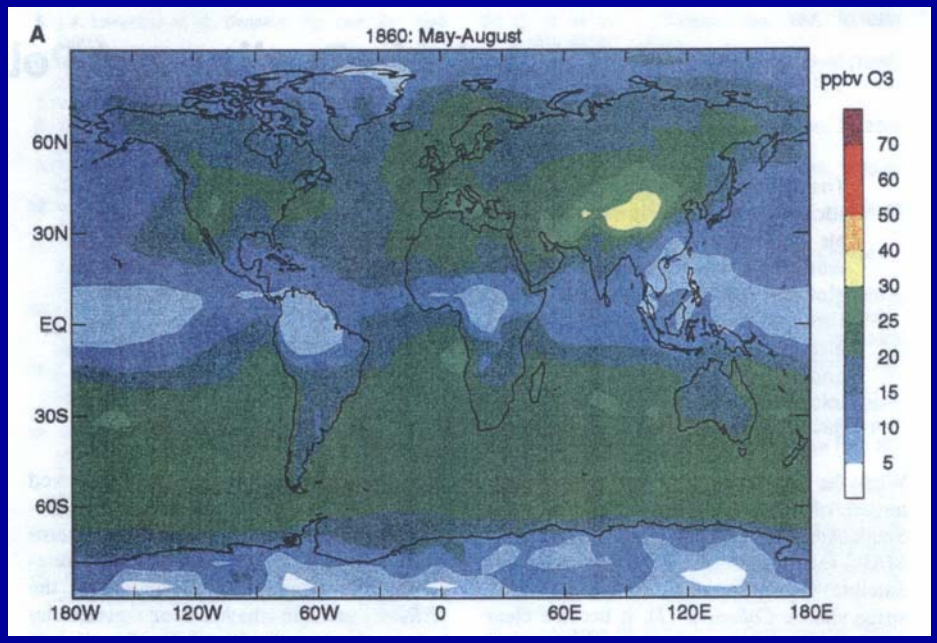
IPCC-TAR (2001), *Climate Change 2001: The Scientific Basis*

Historical Ozone Concentrations

- 1880s:
15-25 ppb

- 1993:
40-50 ppb

Akimoto (2003) *Science*



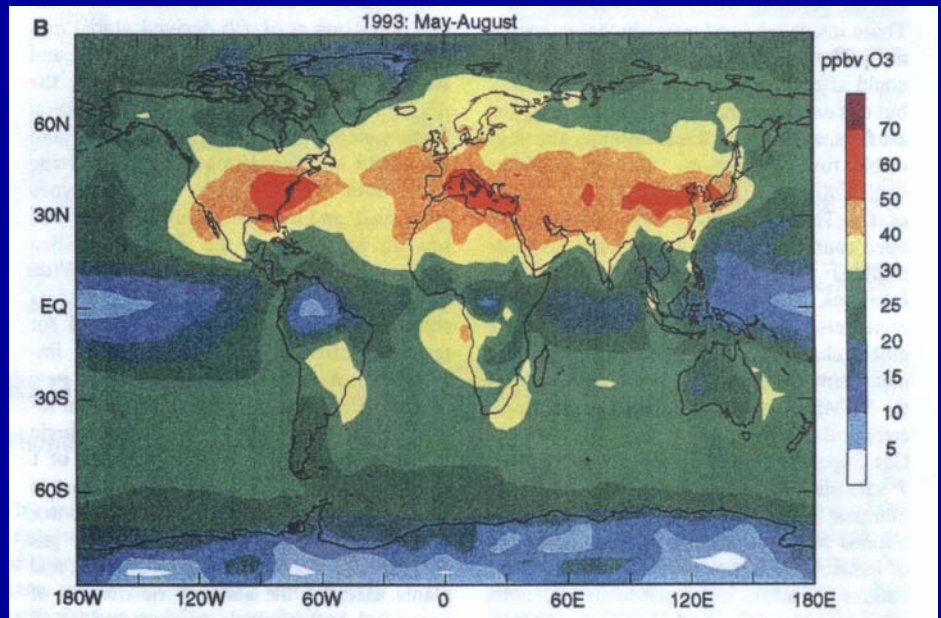
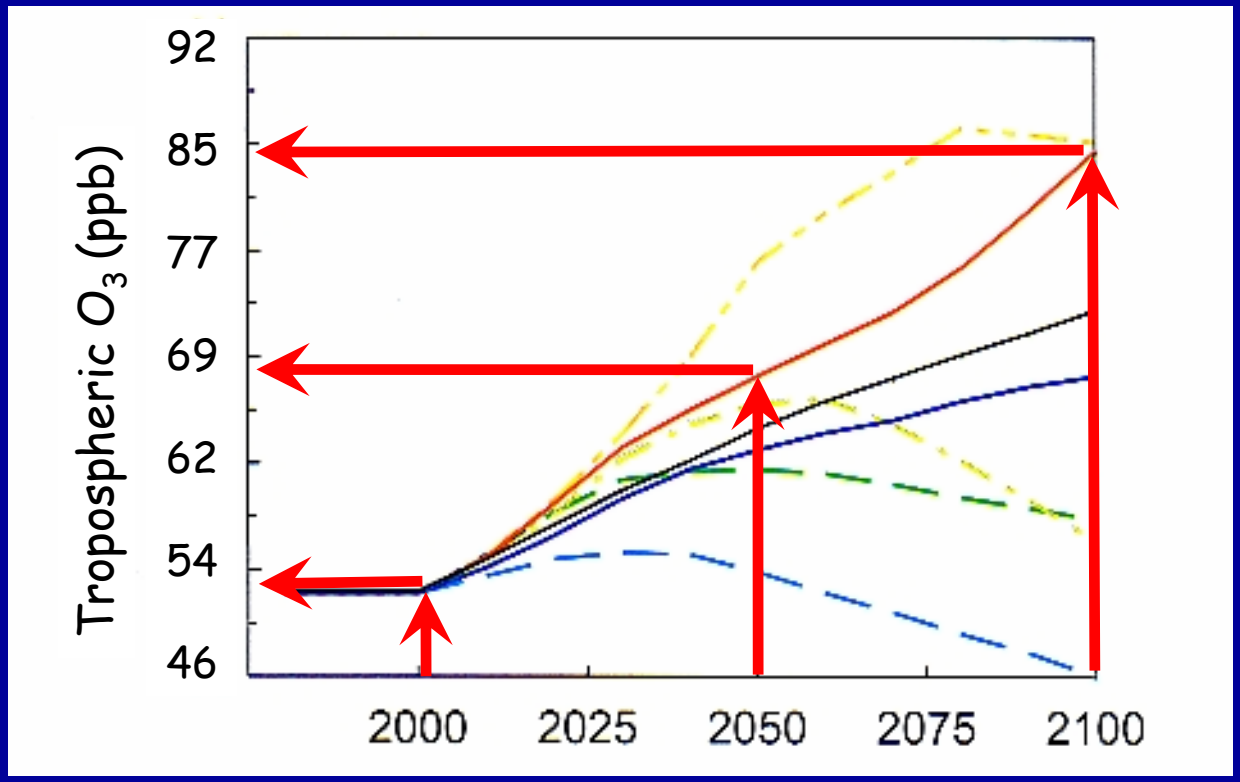
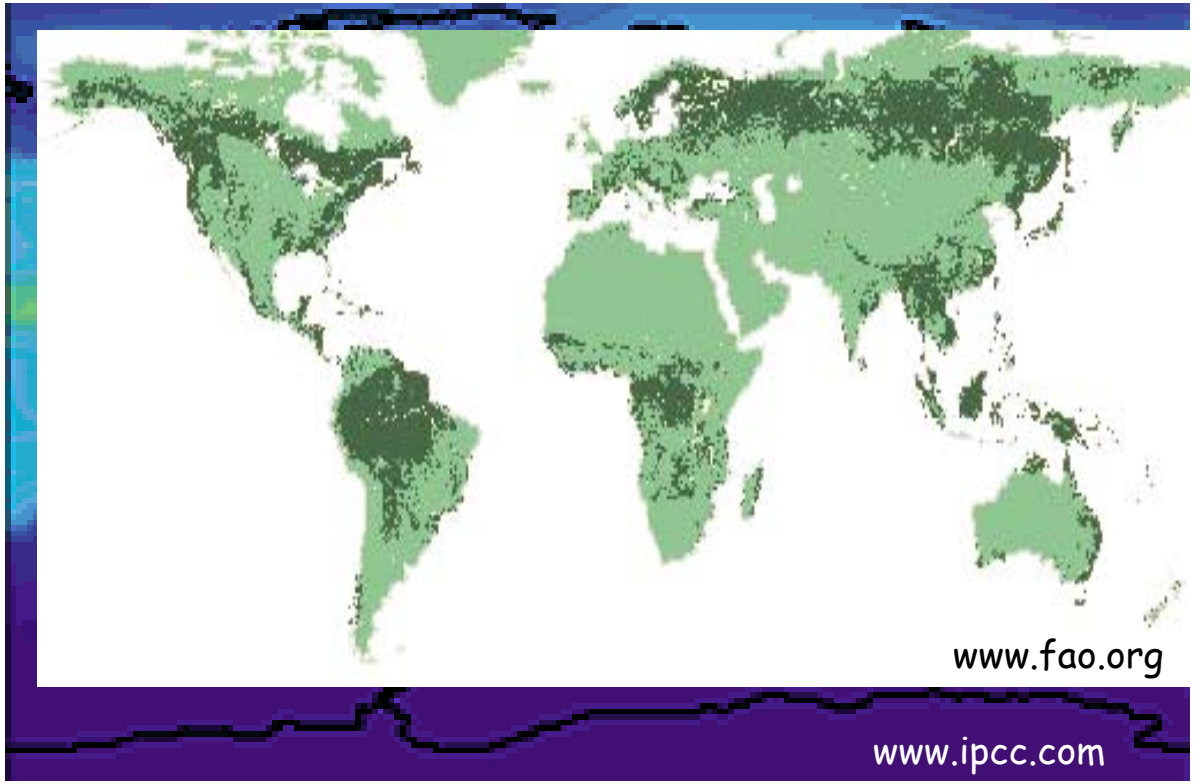


Fig. 1. Model-calculated surface O_3 during the growing season in the Northern Hemisphere (May through August) in (**A**) 1860 and (**B**) 1993 (*13*).

Tropospheric Ozone As Projected by IPCC-TAR



IPCC-TAR (2001), *Climate Change 2001: The Scientific Basis*

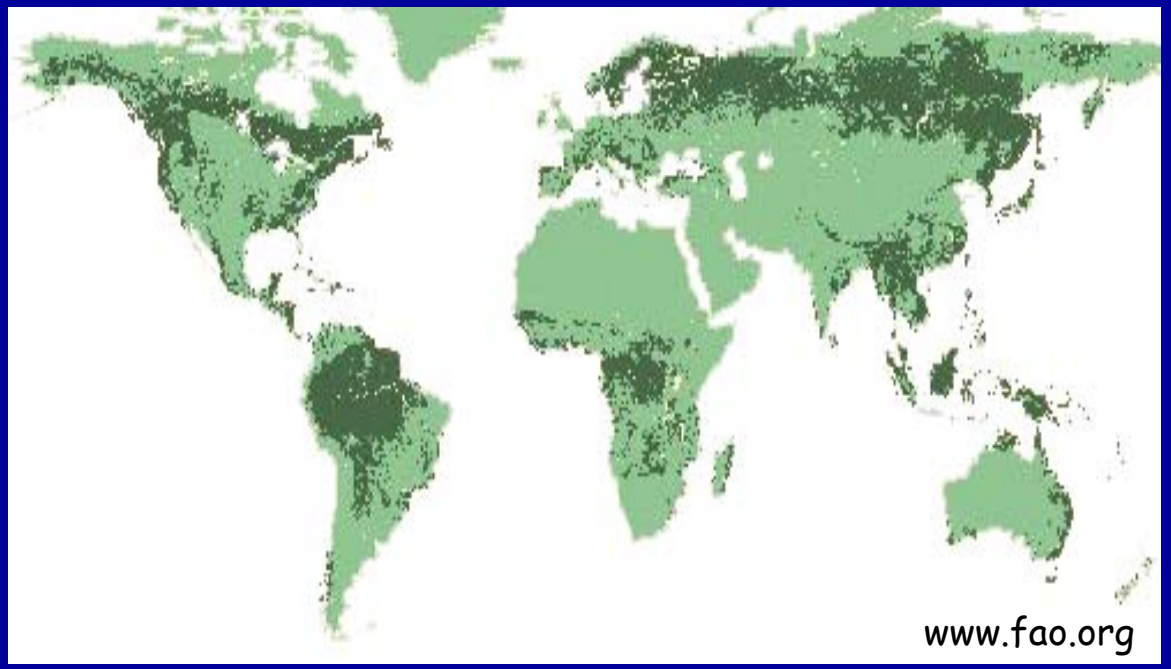


Global Forest Distribution

0 15 30 45 60

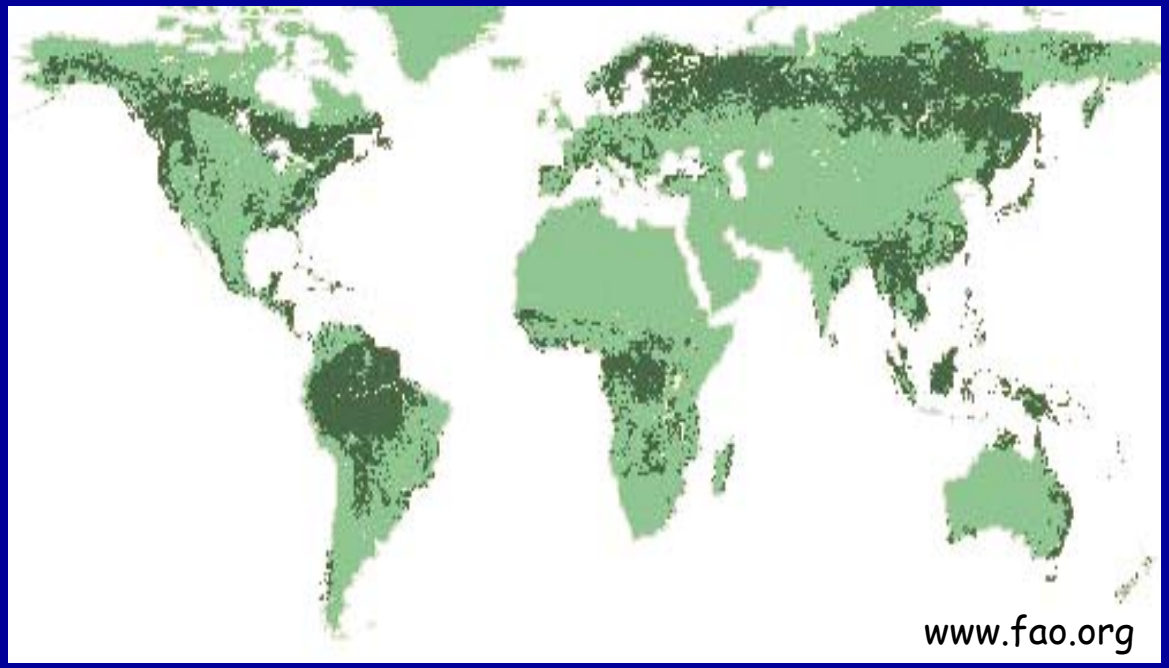
Increase in Tropospheric Ozone (ppb) for 2000-2100

30% Global Land Area



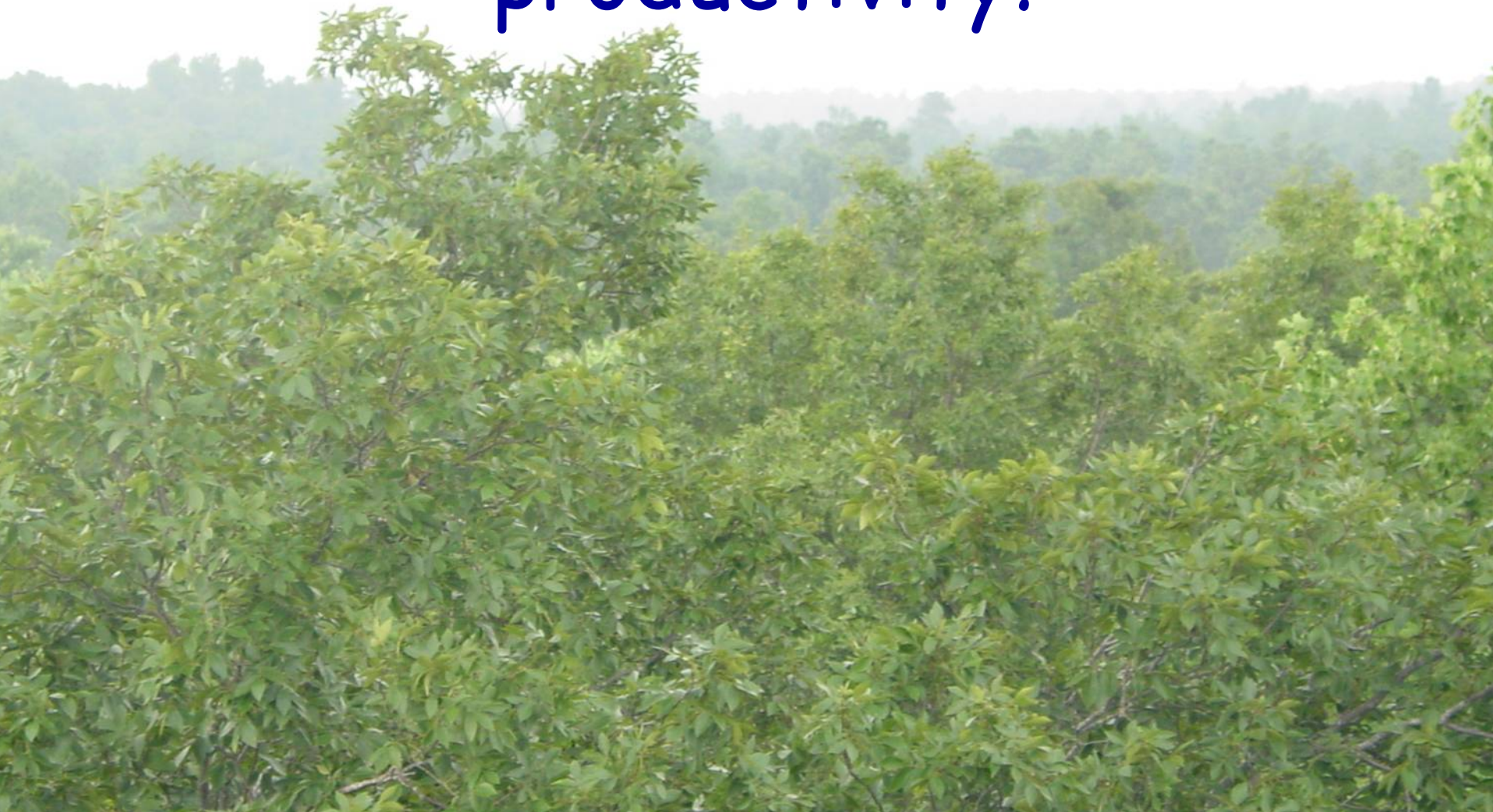
Global Forest Distribution

30% Global Land Area



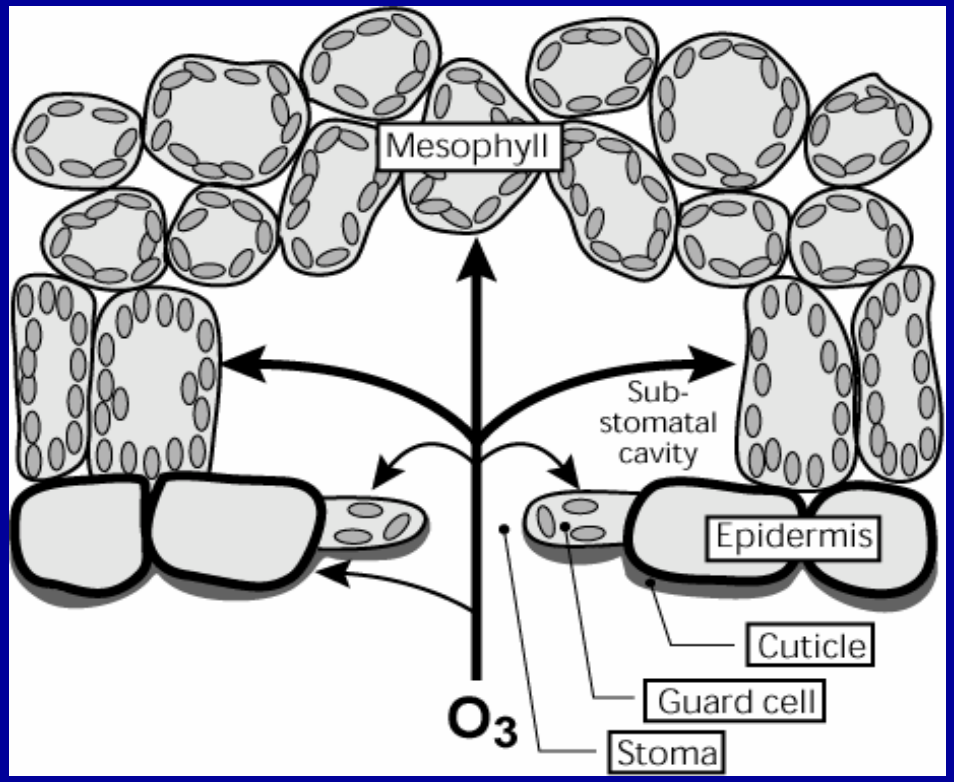
70% Terrestrial Net Primary Production

What is the impact of tropospheric [O_3] on tree productivity?



Ozone must gain entry inside the leaf before damage can occur

- Readily reacts with aqueous surfaces to form Reactive Oxygen Species (ROS)
- Up-regulation of anti-oxidant defenses
- Reduction in Rubisco activity/content
- Accelerated leaf senescence



Adapted from Long, S.P. and S.L. Naidu (2002), In: *Air Pollution and Plant Life*

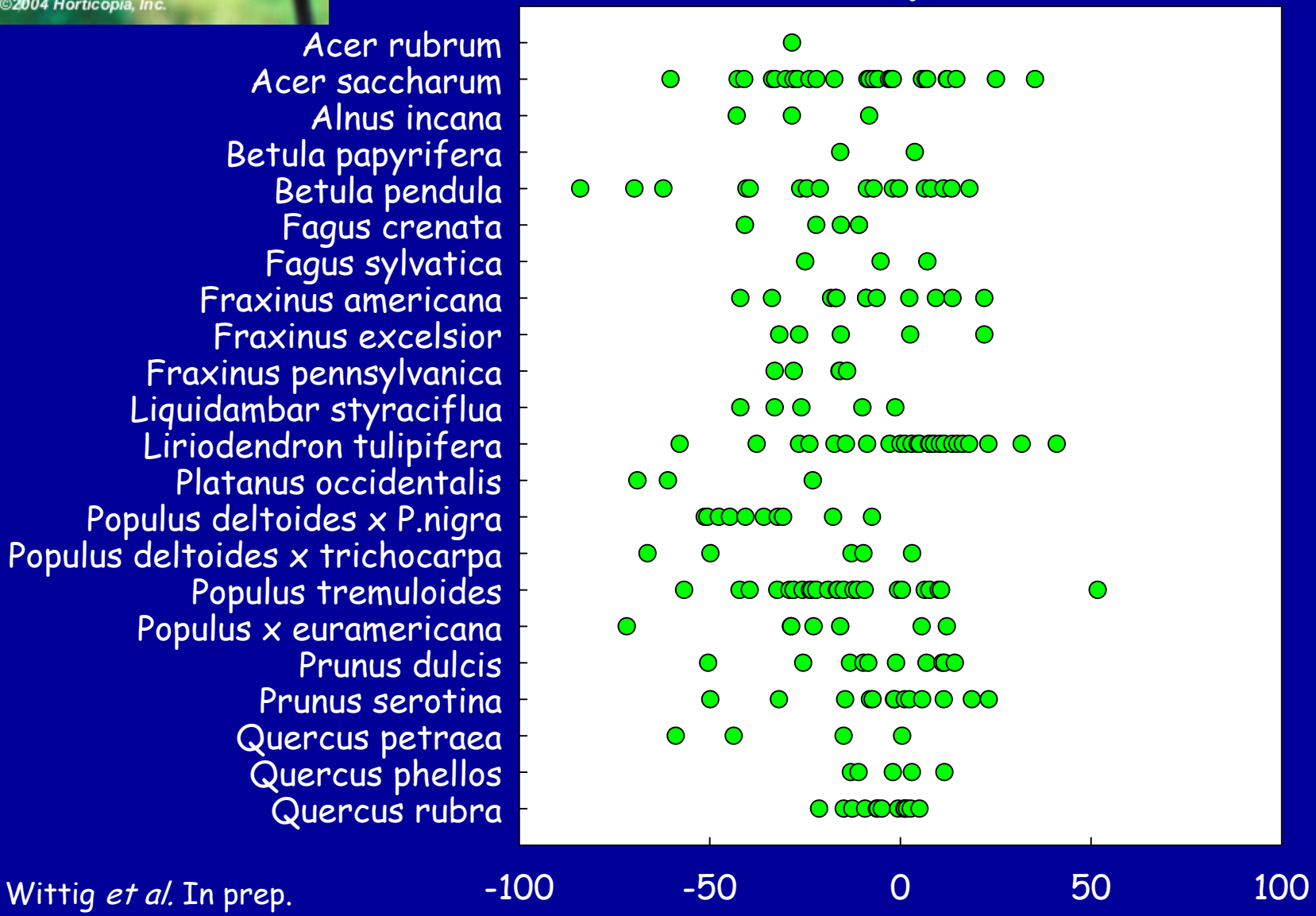
What is the impact of tropospheric [O_3] on tree productivity?

Has the impact of tropospheric [O_3] on tree productivity been recorded in the literature?

Has the impact been observed? Literature Survey

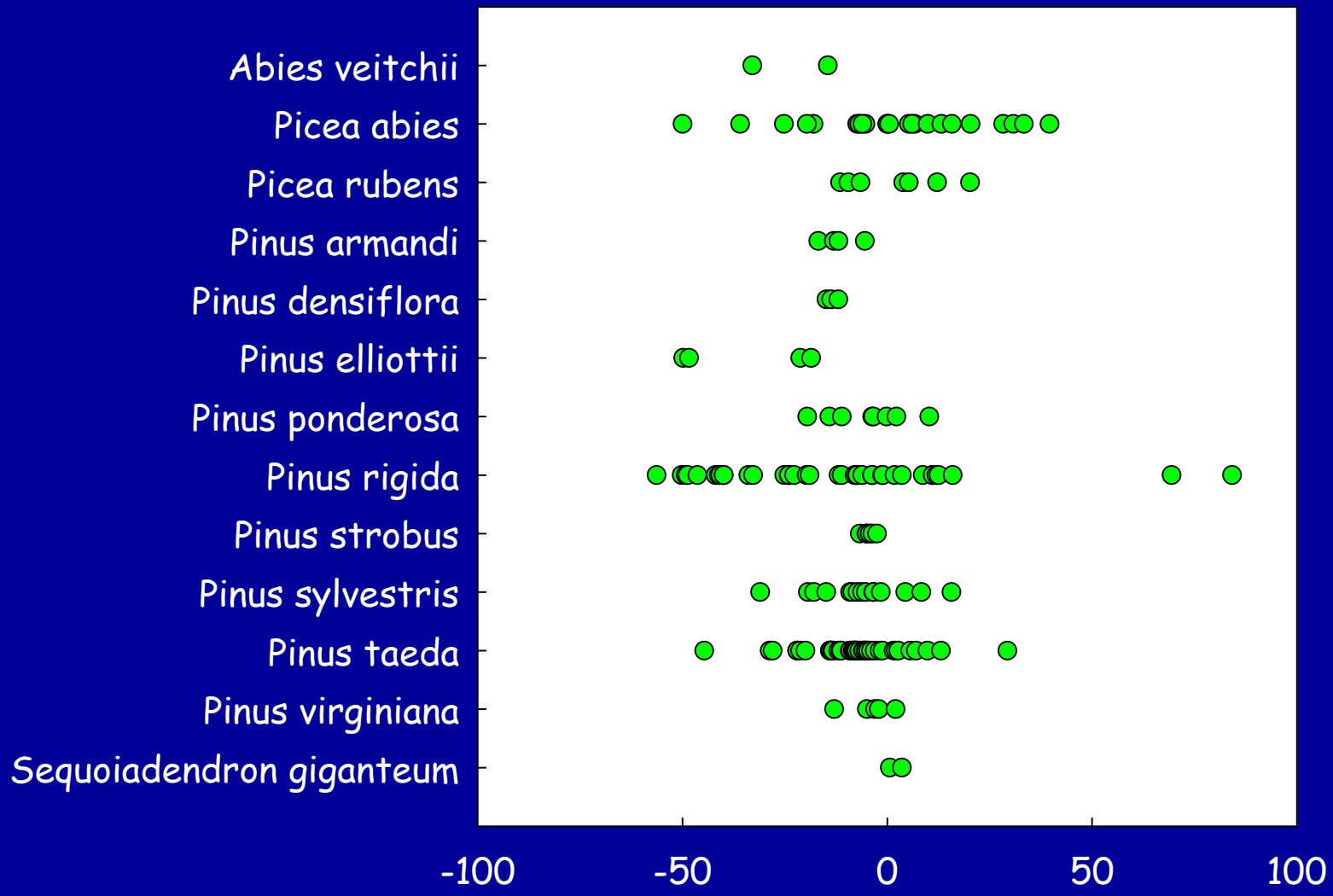
- >1000 primary research articles from University of Illinois at Urbana-Champaign library
- Impact on biomass, physiology and nutrient characteristics
- NO Consensus; High variability

Angiosperm Trees: Total Biomass



Wittig *et al.* In prep.

Gymnosperm Trees: Total Biomass



Wittig *et al.* In prep.

Hundreds of observations extracted from the literature

- Total dry weight
- Root dry weight (Coarse + Fine)
- Shoot dry weight (Foliage + Branch + Trunk)
- Aboveground-woody dry weight (Branch + Trunk)
- Foliage dry weight
- Root to Shoot Ratio
- Height
- Diameter
- Leaf Area
- Stomatal Conductance

Why so much variability?

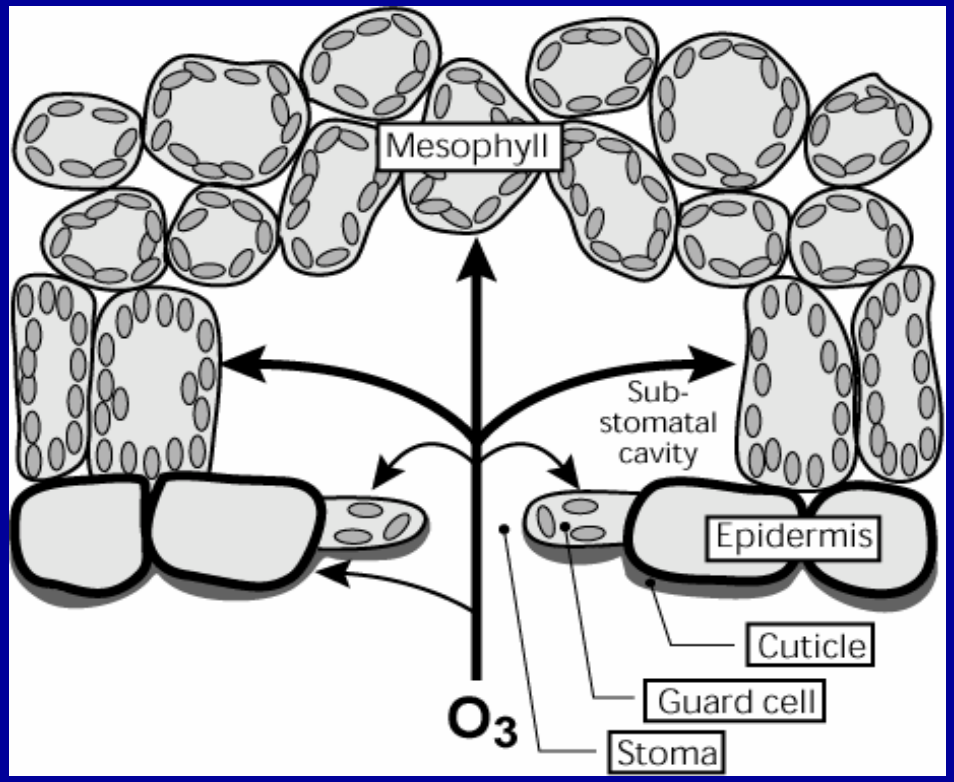
- Functional group: angiosperm or gymnosperm

Why so much variability?

- Duration of Exposure: hours, days, months, years
- Enclosure: open-top chamber, indoor growth chamber, FACE
- Pot Size: small pots, ground
- Tree Age; Leaf Age

To cause damage, O_3 must gain entry…

- Any environmental condition that reduces stomatal conductance should reduce O_3 damage
  - Drought



Adapted from Long, S.P. and S.L. Naidu (2002), In: *Air Pollution and Plant Life*

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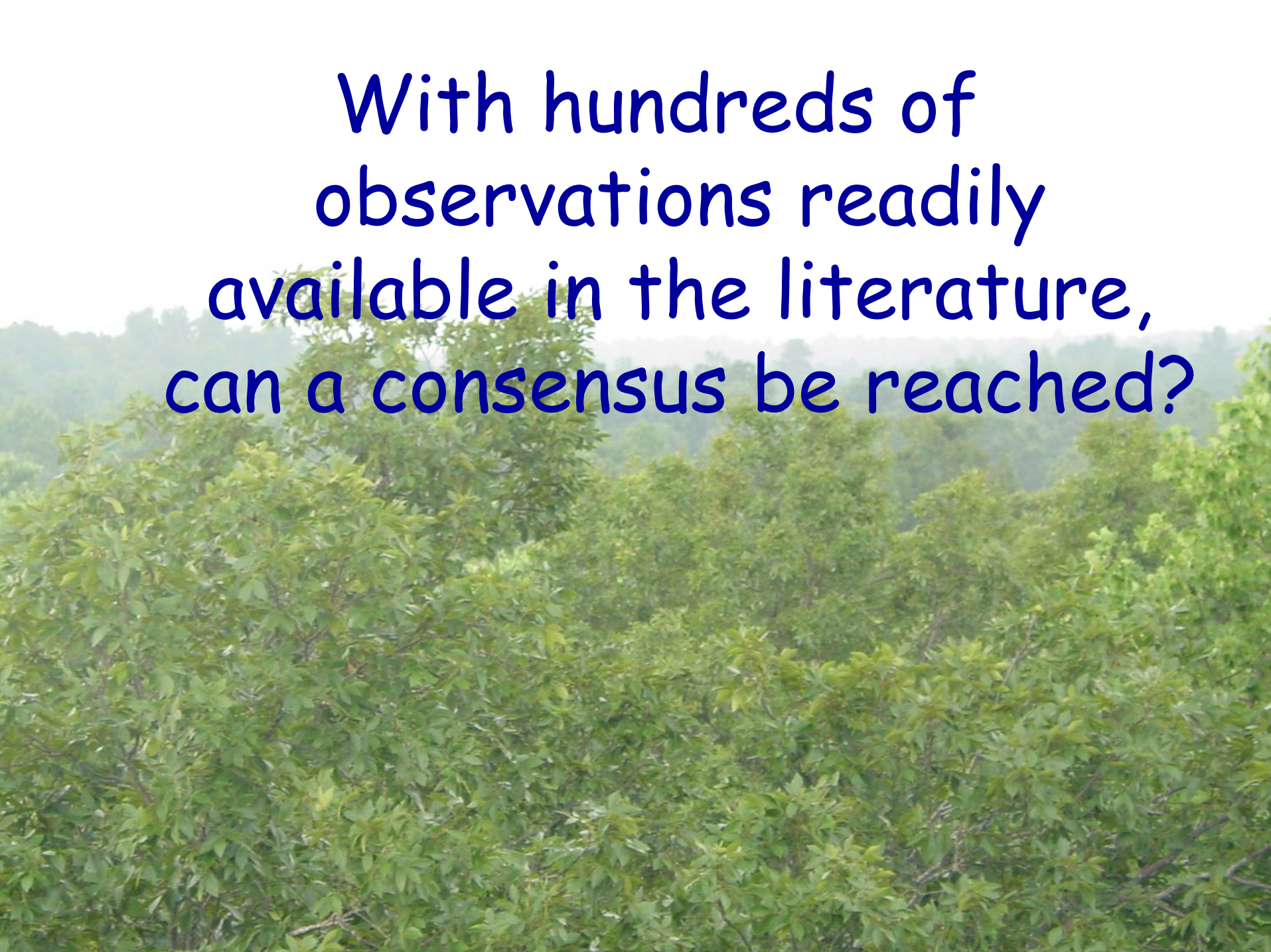
✓Has the impact of tropospheric [O_3] on tree productivity been recorded in the literature?


With hundreds of observations readily available in the literature, can a consensus be reached?

Meta-analysis

- Statistical tool used to determine a mean relative response from different experiments investigating the effect of the same treatment
- Developed in the medical and social sciences
- Increasingly used in environmental and ecological sciences (Morgan *et al.*, 2003 *Plant, Cell and Environment*; Ainsworth & Long, 2005 *New Phytologist*)

Web of Science
Silver Platter

Search:
Ozone, trees
production,

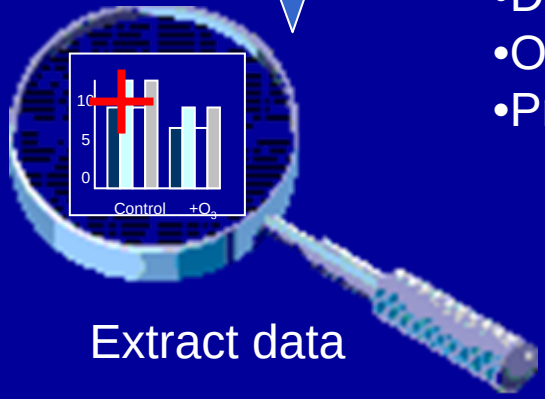
TM

Collect articles from
Univ. Illinois Library

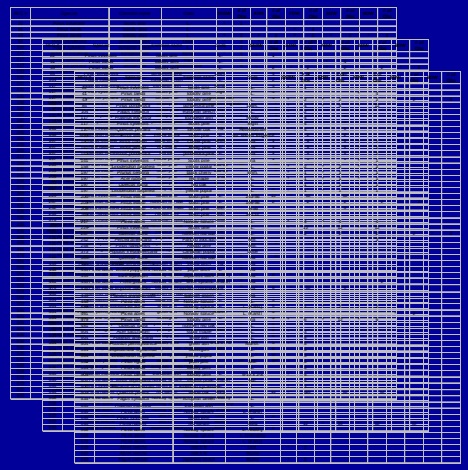
96

Filter studies for
adequate detail of
•Replication
•Design
•Ozone concentration
•Production data

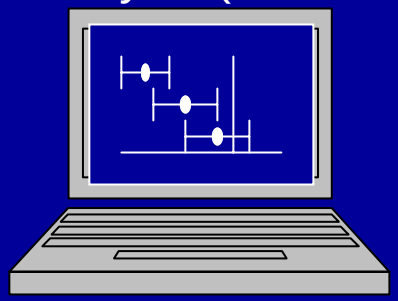
Extract data



Database



Summarize statistical meta-
analysis (MetaWin™)



Statistical Tool: Meta-analysis

- Observation of mean effect:
  $\overline{X}_T$= Treatment [O_3]
  $\overline{X}_C$= Control [O_3]

- Estimate mean treatment Effect Size (E)

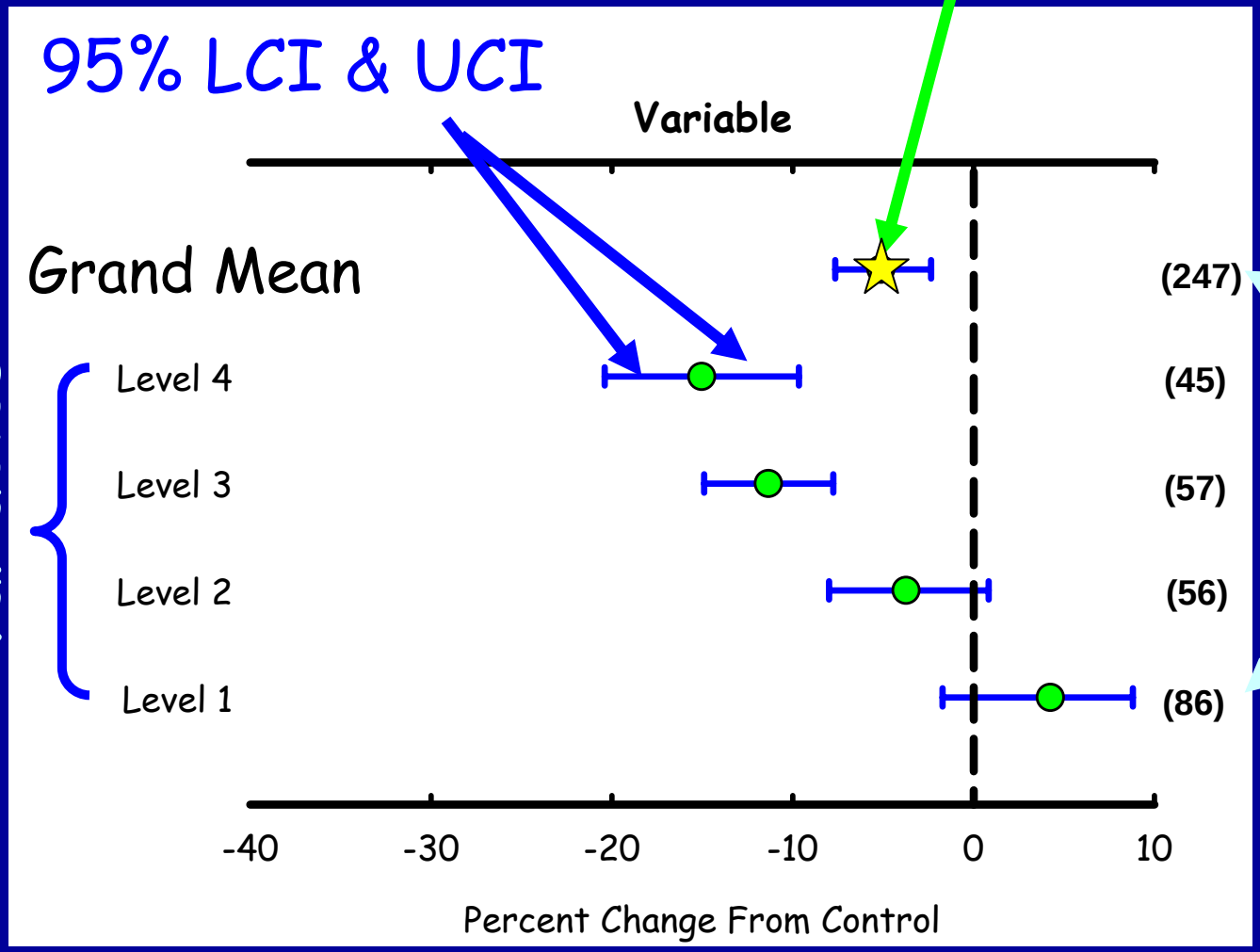
$$E = \ln r = \ln (\overline{X}_T/\overline{X}_C)$$

- % Change From Control =[(r – 1) *100]

Sample figure

[(*r* - 1)*100]

95% LCI & UCI



Categorical Variables

Degrees of freedom

"Zooming In" to reach a consensus

- Grand Mean: All Observations, including all types of experiments
- Ozone Concentration
- Functional Groups
- Additional Stress Treatments
- Stomatal Conductance

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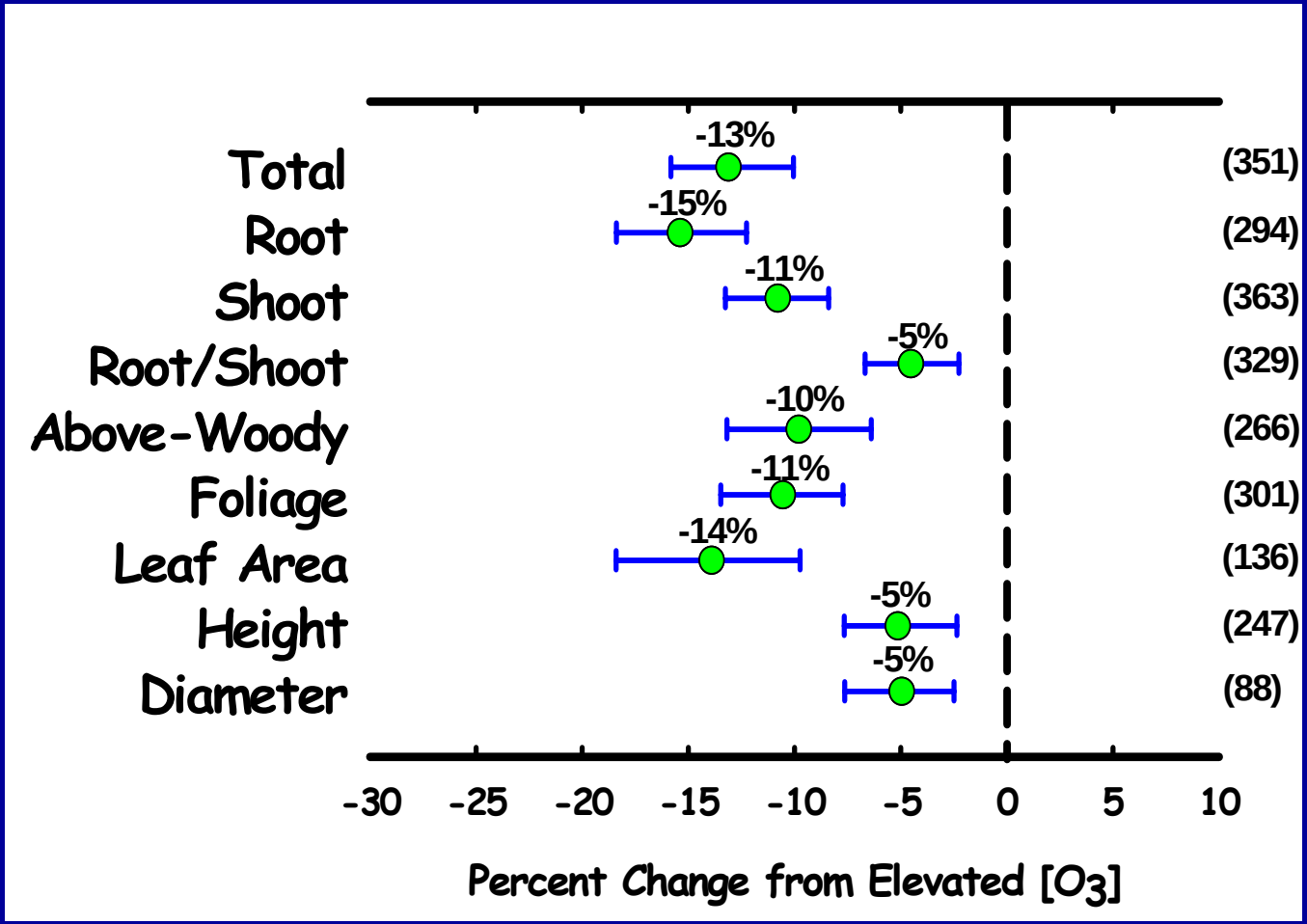
Grand Means


Total
Root
Shoot
Root/Shoot
Above-Woody
Foliage
Leaf Area
Height
Diameter
-13%
-15%
-11%
-5%
-10%
-11%
-14%
-5%
-5%
(351)
(294)
(363)
(329)
(266)
(301)
(136)
(247)
(88)
-30
-25
-20
-15
-10
-5
0
5
10
Percent Change from Elevated [O3]

"Zooming In" to reach a consensus

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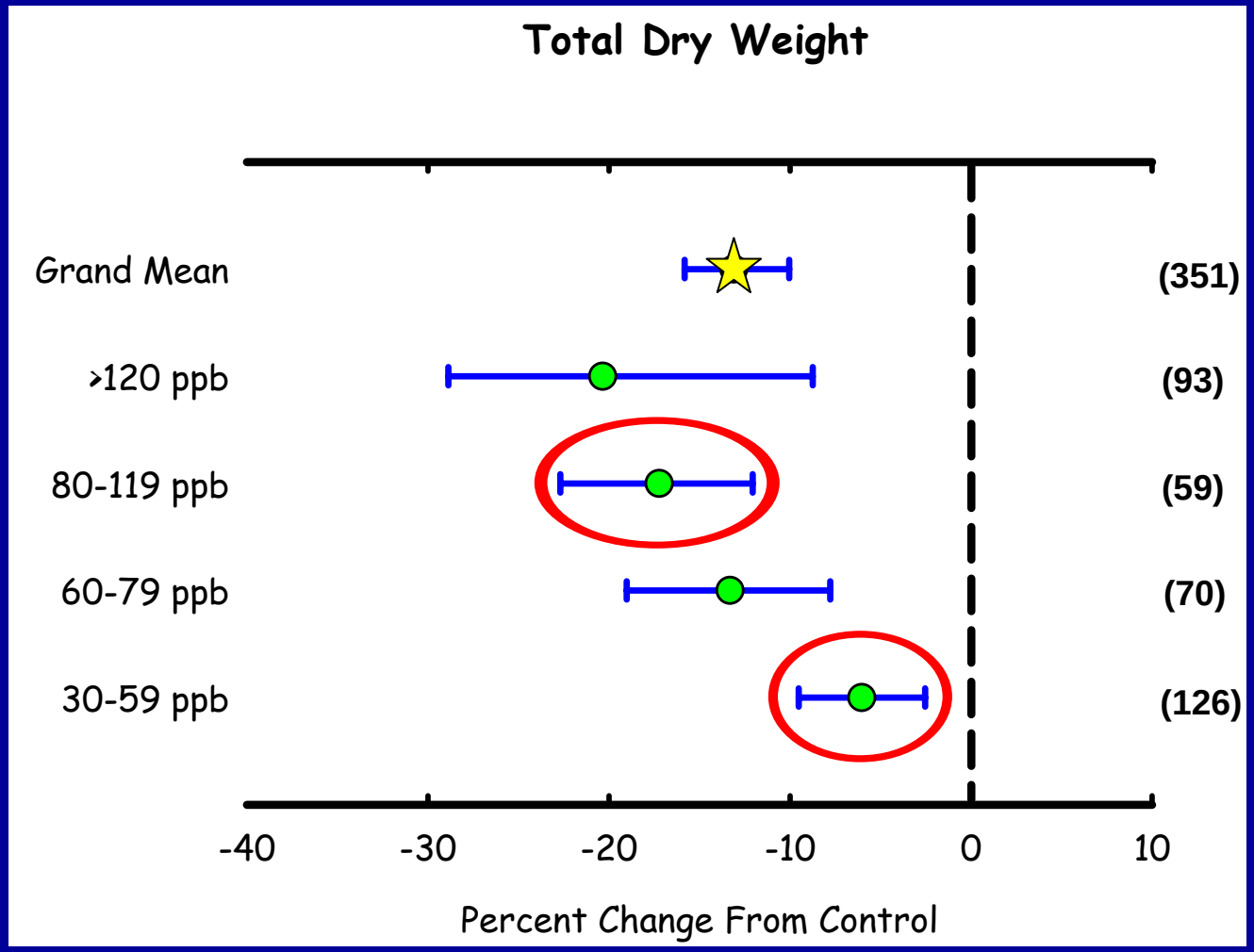
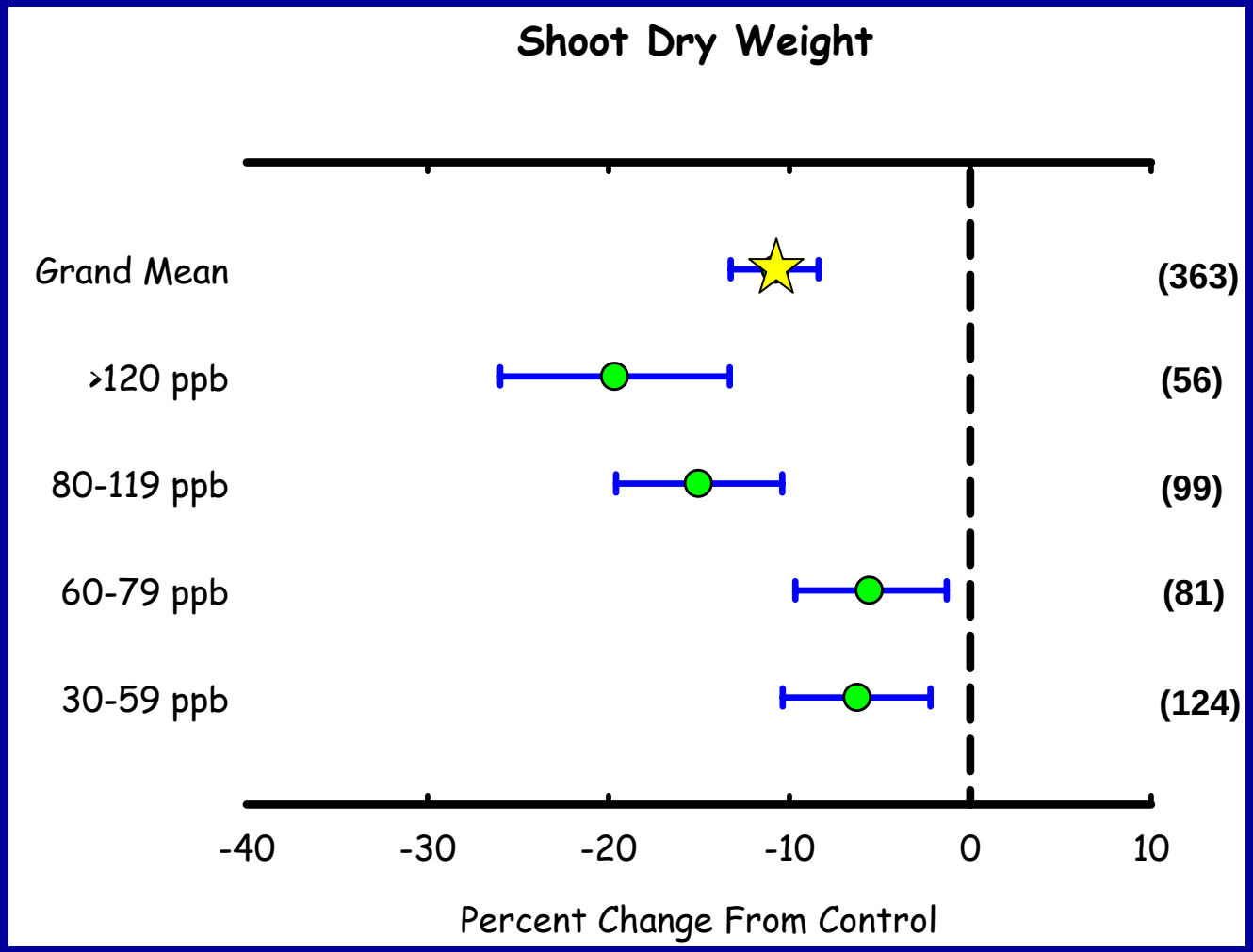
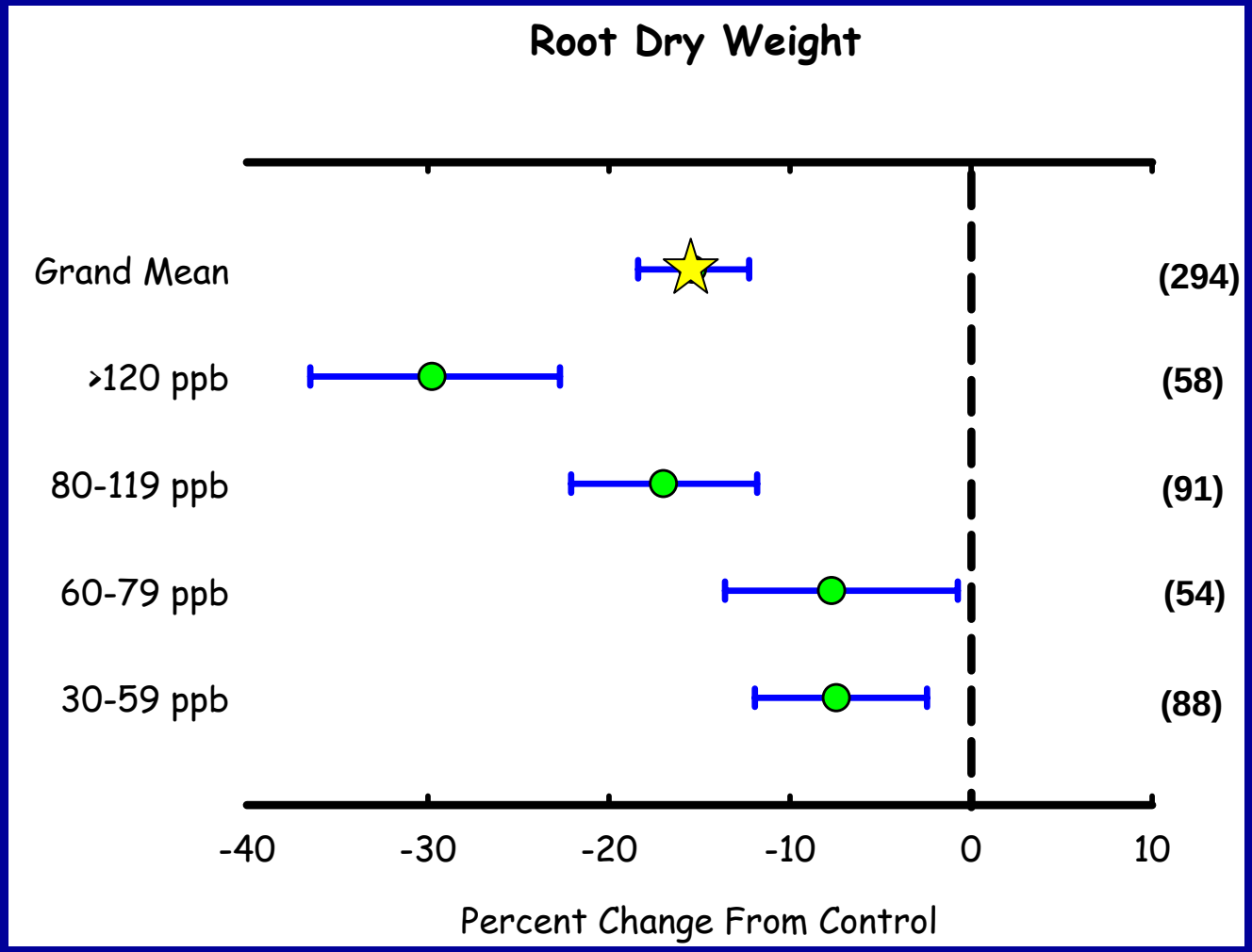
Ozone Concentration



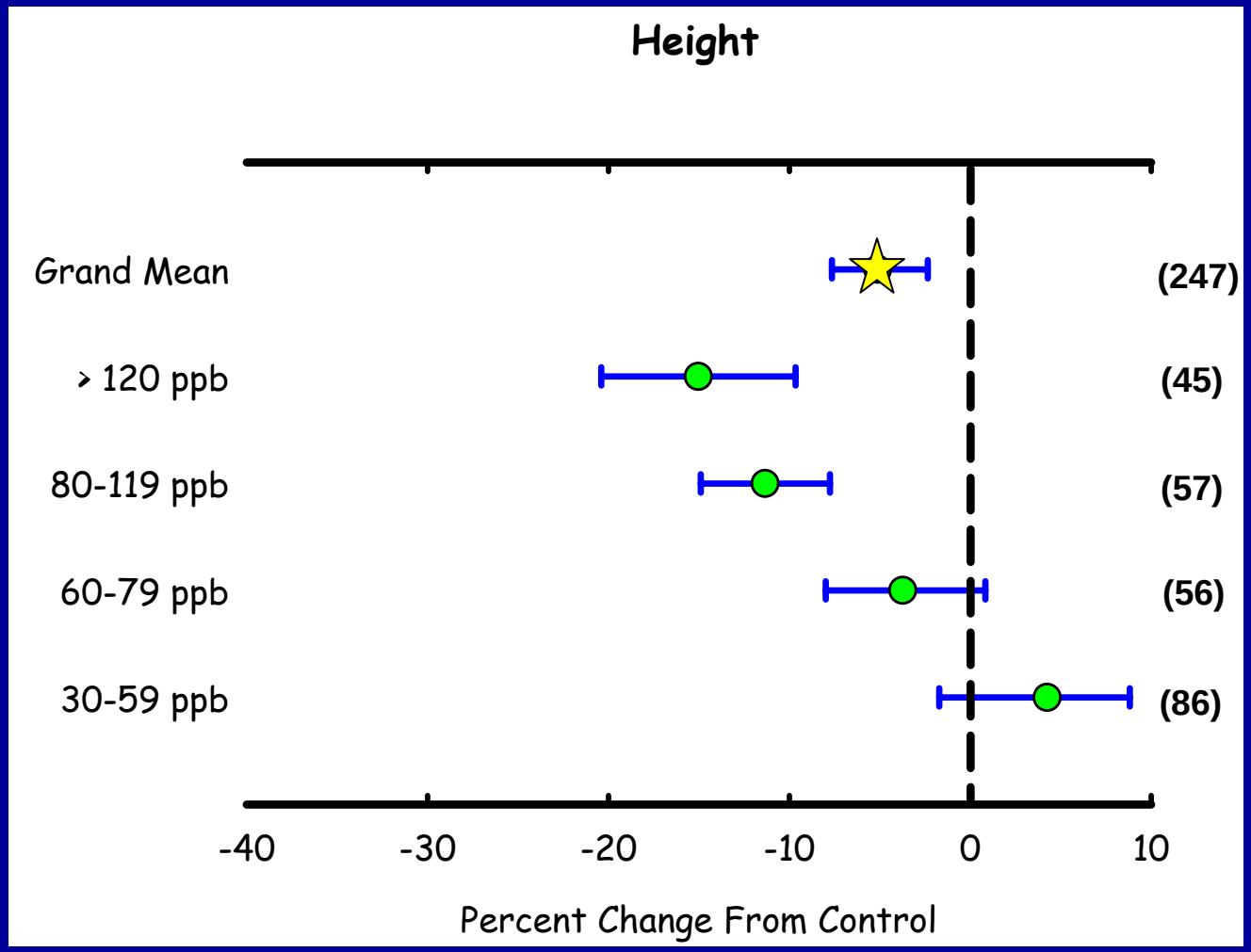
Ozone Concentration

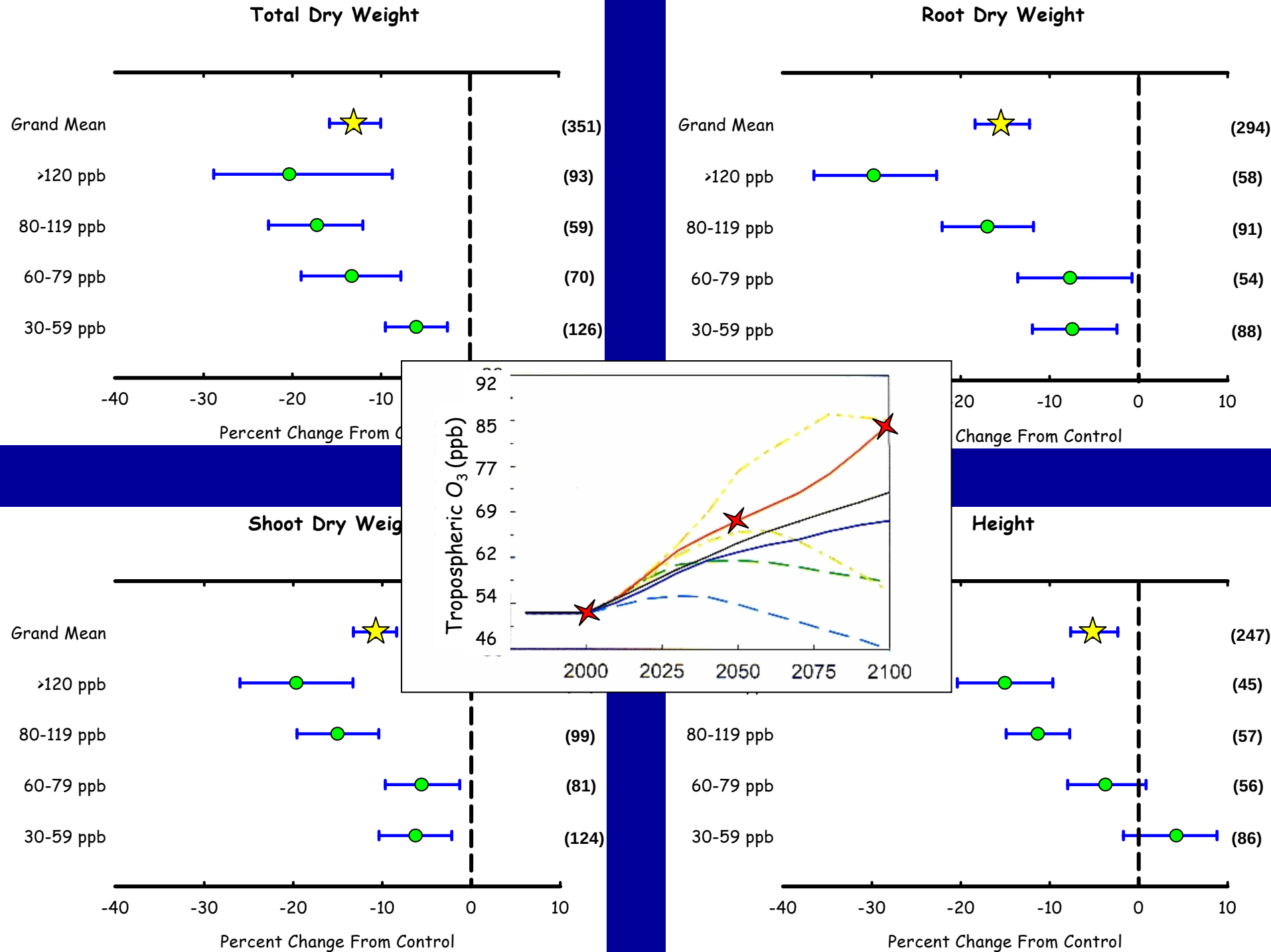


Ozone Concentration



Ozone Concentration

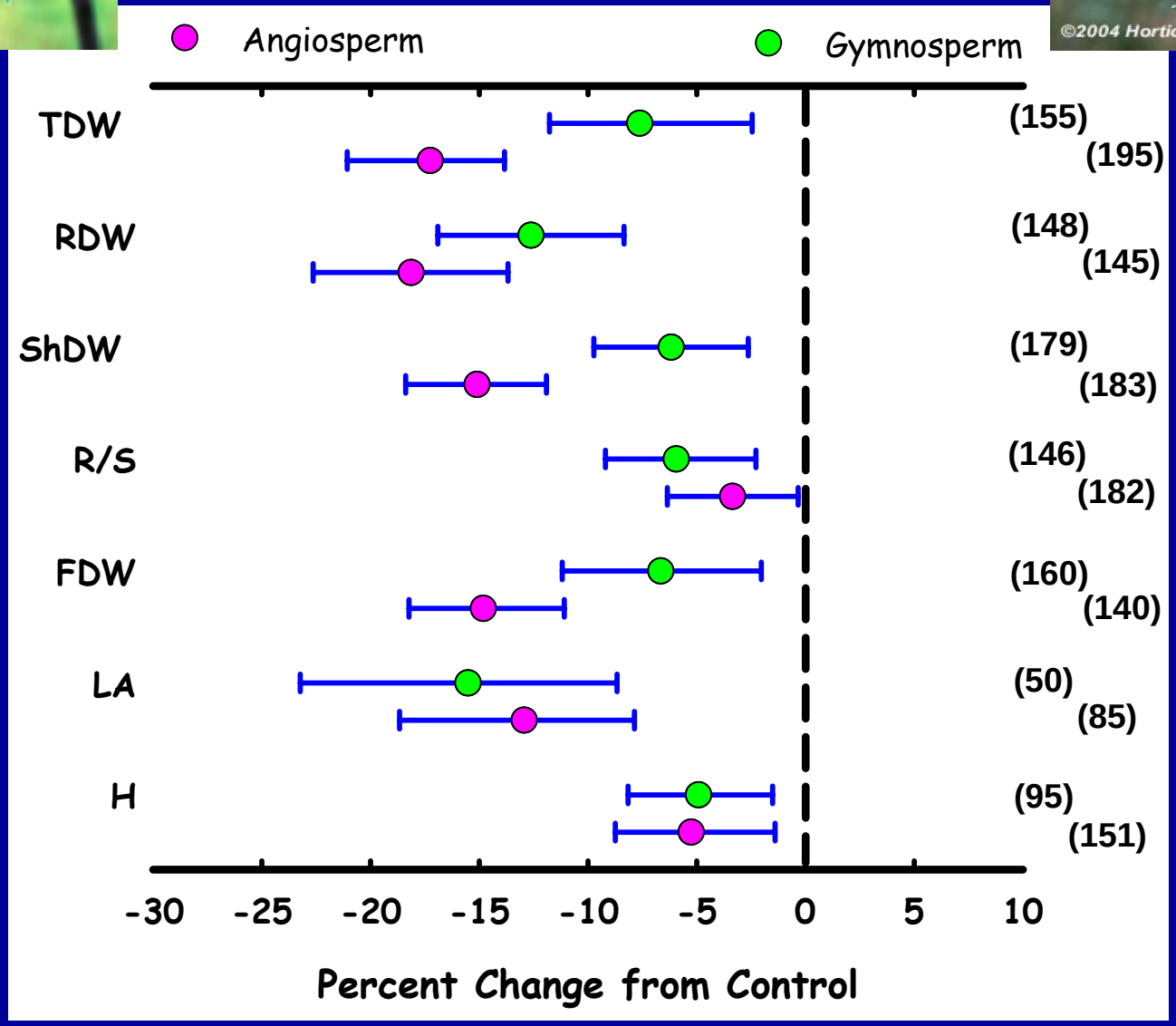



Total Dry Weight
Grand Mean
>120 ppb
80-119 ppb
60-79 ppb
30-59 ppb
(351)
(93)
(59)
(70)
(126)
-40
-30
-20
-10
Percent Change From C
Root Dry Weight
Grand Mean
>120 ppb
80-119 ppb
60-79 ppb
30-59 ppb
(294)
(58)
(91)
(54)
(88)
20
-10
0
10
Change From Control
Tropospheric O_3 (ppb)
92
85
77
69
62
54
46
2000
2025
2050
2075
2100
Shoot Dry Weig
Grand Mean
>120 ppb
80-119 ppb
60-79 ppb
30-59 ppb
(99)
(81)
(124)
-40
-30
-20
-10
0
10
Percent Change From Control
Height
(247)
(45)
(57)
(56)
(86)
-40
-30
-20
-10
0
10
Percent Change From Control

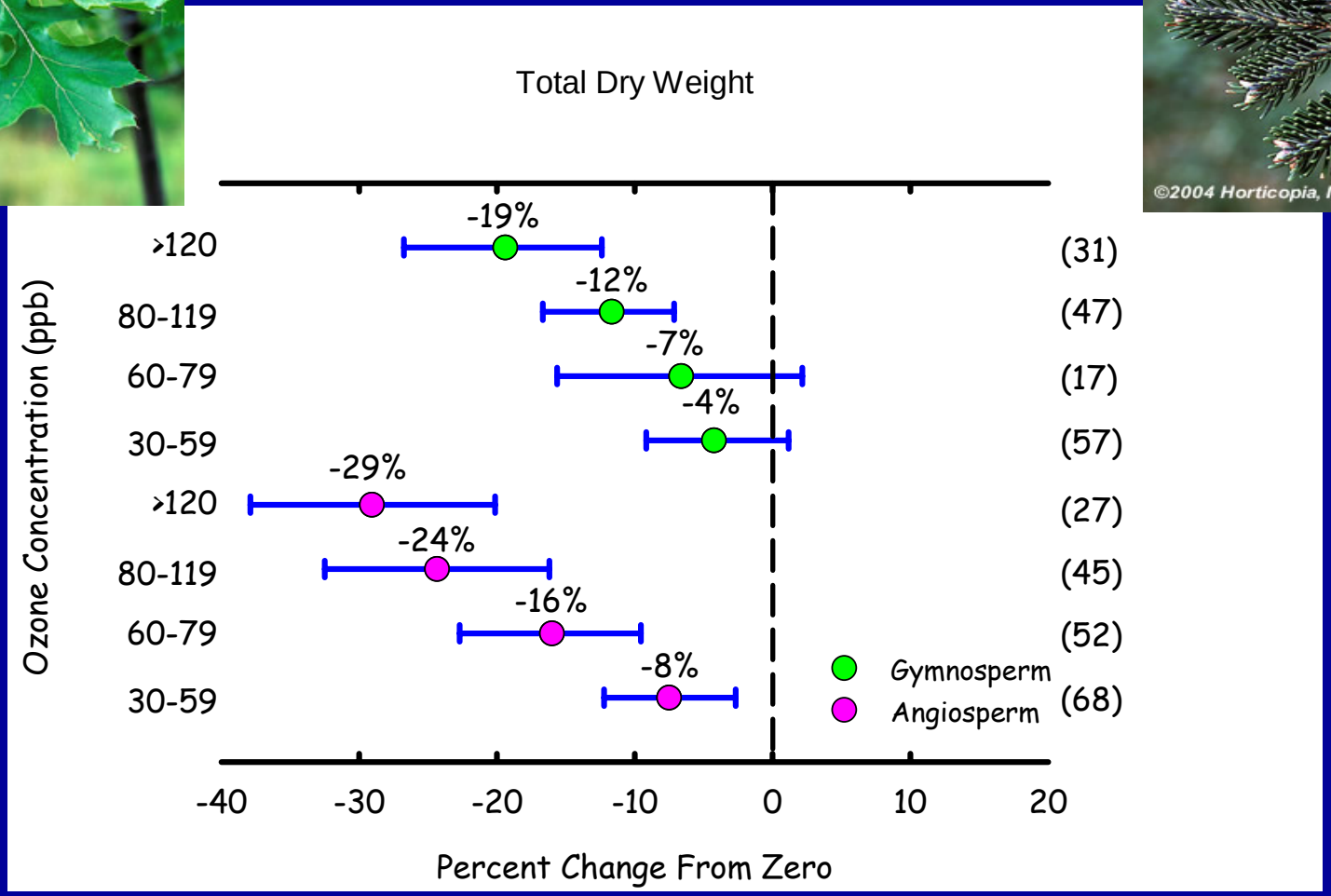
"Zooming In" to reach a consensus

- Grand Mean: All Observations, including all types of experiments
- Ozone Concentration
- Functional Groups
- Additional Stress Treatments
- Stomatal Conductance

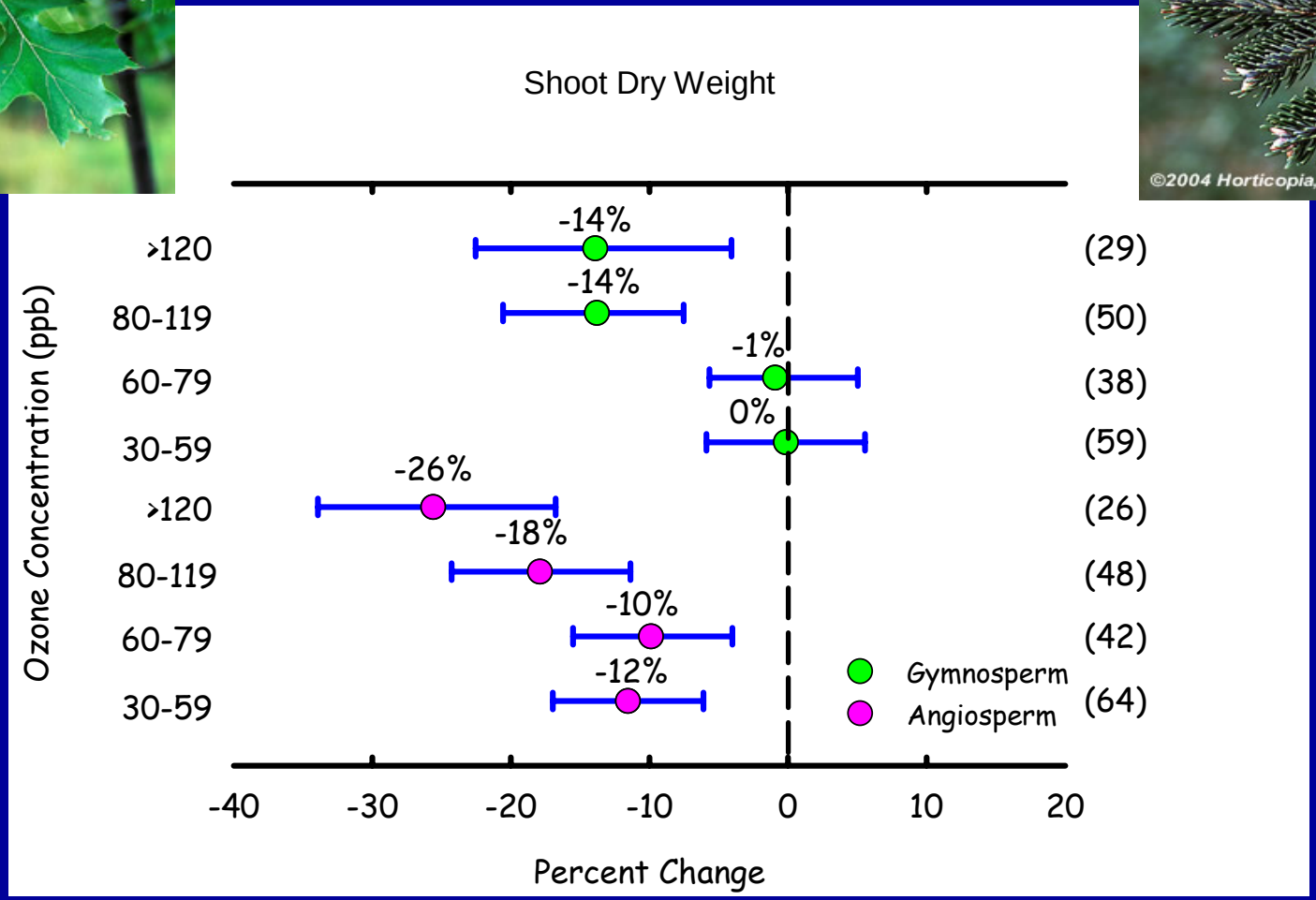
Functional Groups



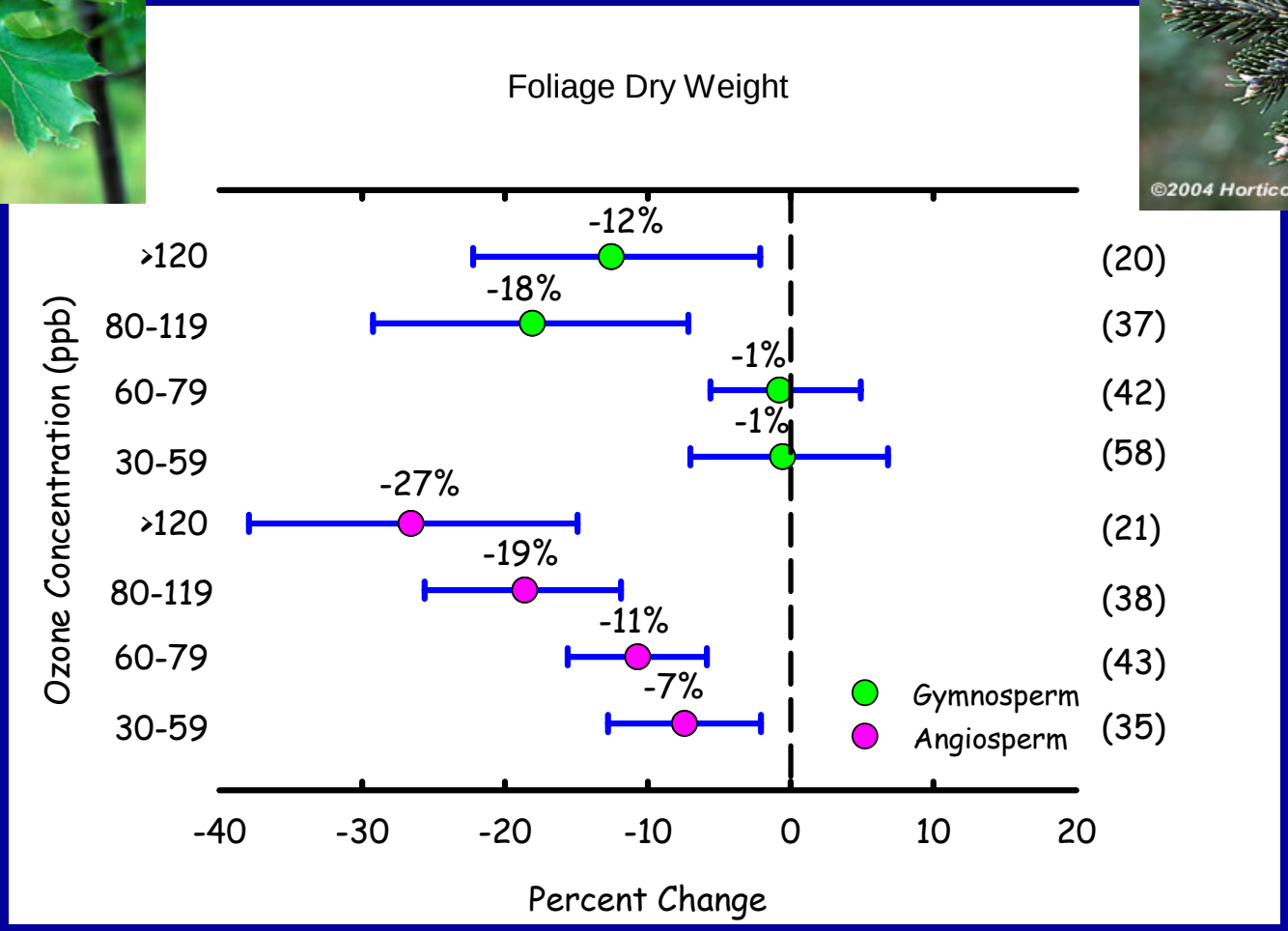
Total Dry Weight: Categorized by Functional Groups and O_3



Shoot Dry Weight: Categorized by Functional Groups and O_3



Shoot Dry Weight: Categorized by Functional Groups and O_3



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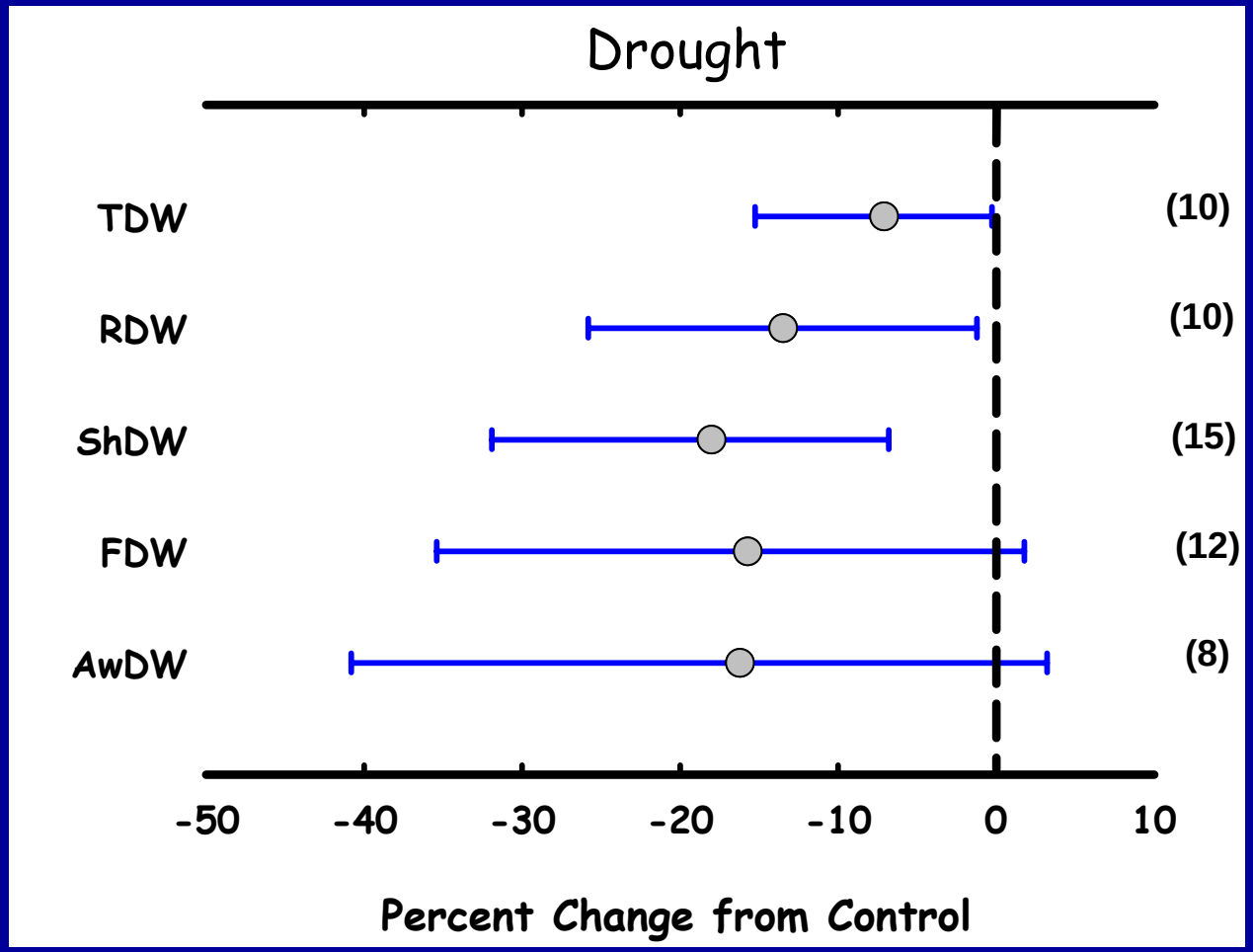
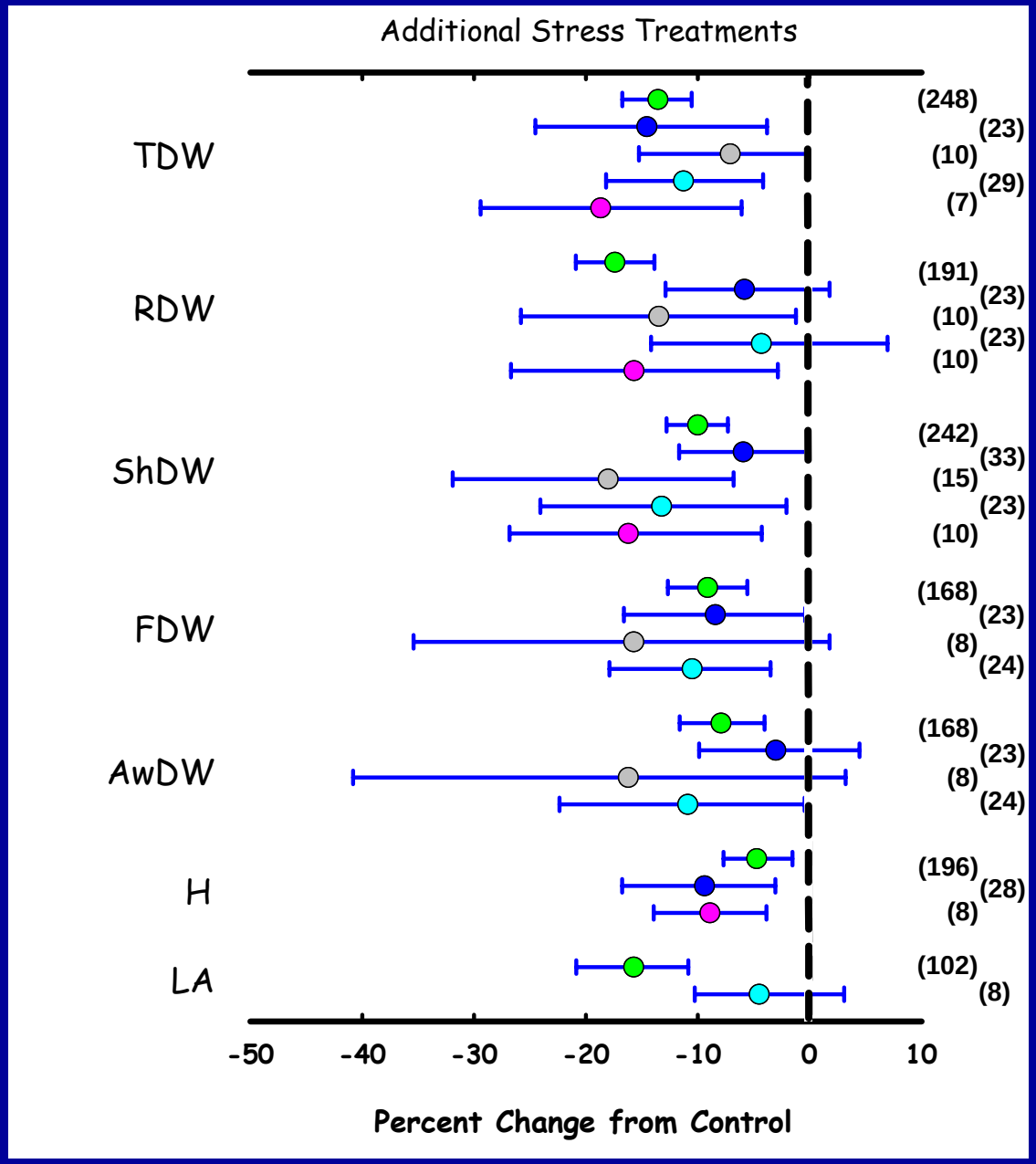
Additional Stress Treatment

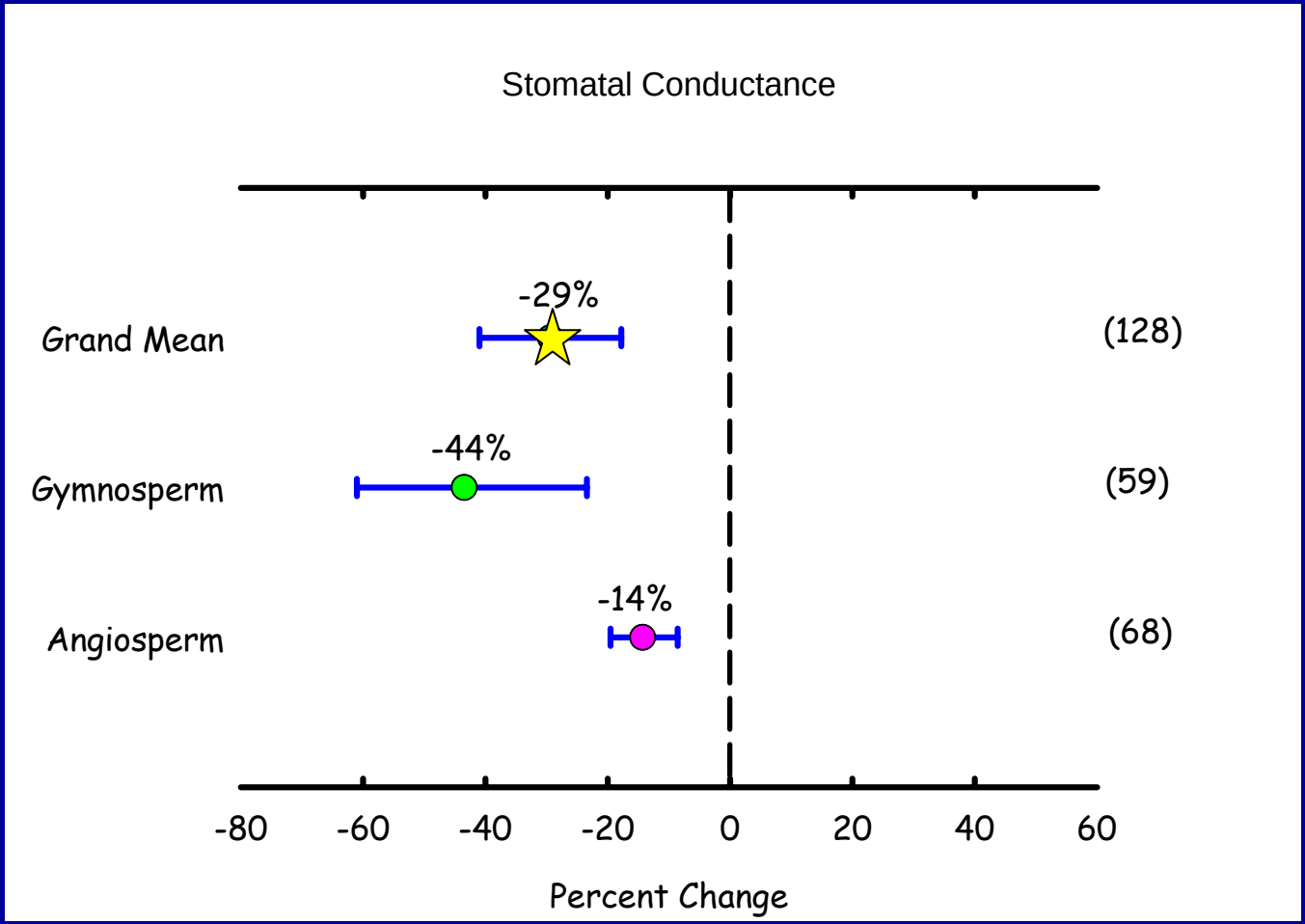



Additional Stress Treatments
TDW
RDW
ShDW
FDW
AwDW
H
LA
(248)
(23)
(10)
(29)
(7)
(191)
(23)
(10)
(23)
(10)
(242)
(33)
(15)
(23)
(10)
(168)
(23)
(8)
(24)
(168)
(23)
(8)
(24)
(196)
(28)
(8)
(102)
(8)
-50
-40
-30
-20
-10
0
10
Percent Change from Control
No Additional Stress
Acid Rain
Drought
Low Fertilizer
Elevated CO_2

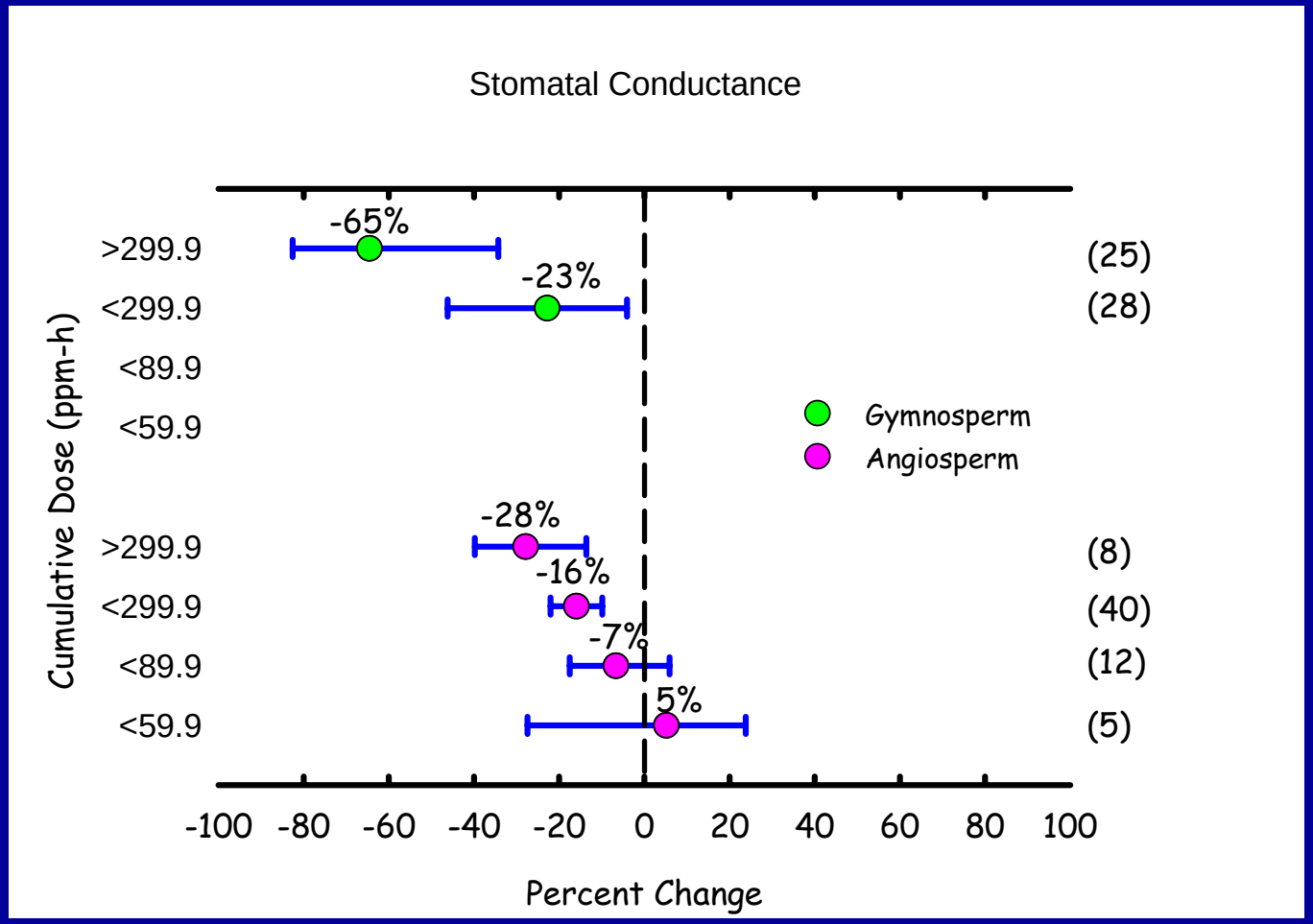
"Zooming In" to reach a consensus

- Grand Mean: All Observations, including all types of experiments
- Ozone Concentration
- Functional Groups
- Additional Stress Treatments
- Stomatal Conductance

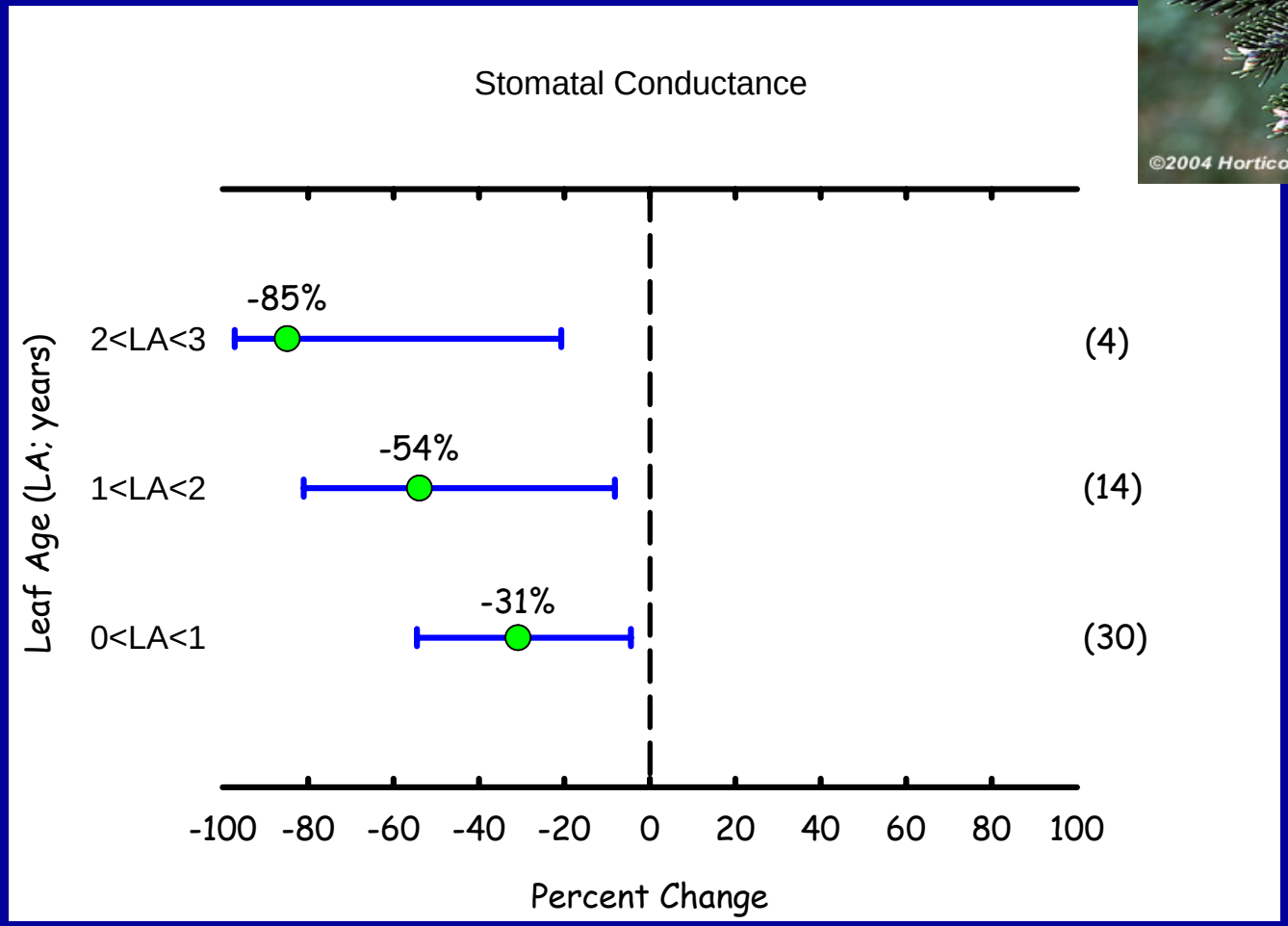
The Next Phase Part 1: Impact of ozone on stomatal conductance



Impact of Cumulative Dose on Stomatal Conductance



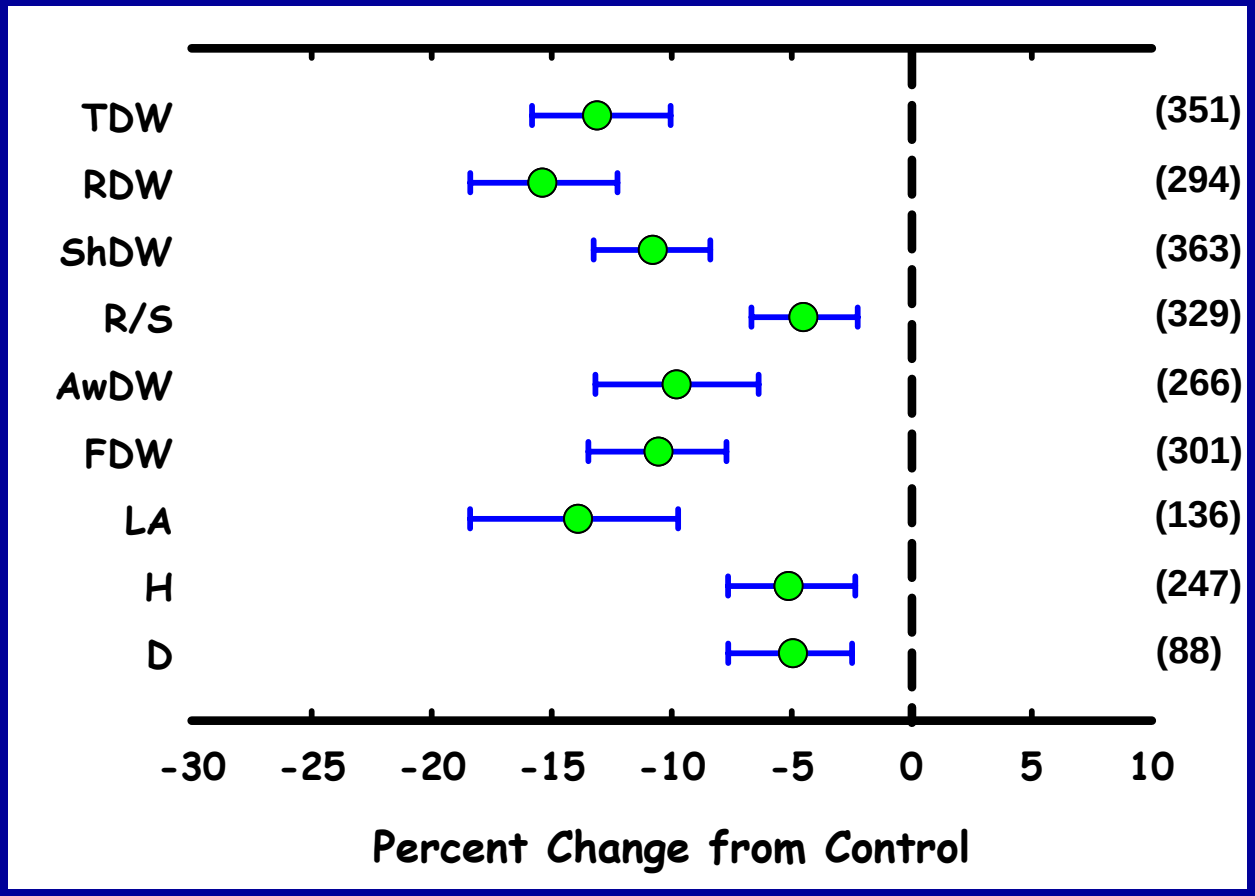
Change in stomatal conductance with leaf age…



Conclusions: What is the consensus?

1. Ozone reduces tree productivity.
2. Productivity is more sensitive at higher concentrations.
3. Angiosperms are more sensitive than gymnosperms.
4. Limited observations in the literature make reaching a consensus on how interactive stresses influence the response of trees to Ozone difficult.
5. Role of stomatal conductance variable: ozone dose, functional group and leaf age.

Consensus 1: Ozone reduces tree productivity.



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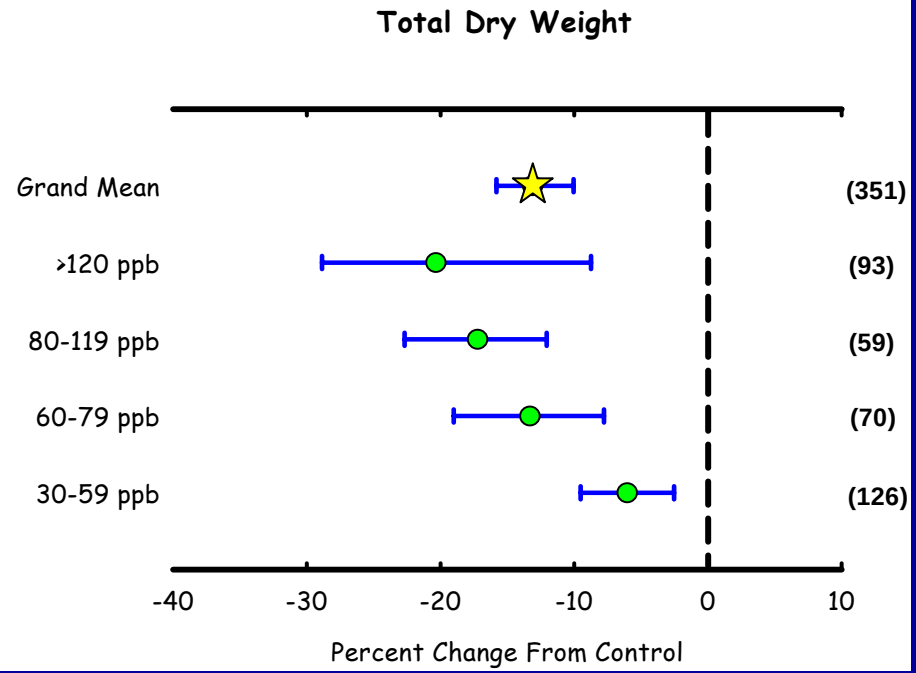
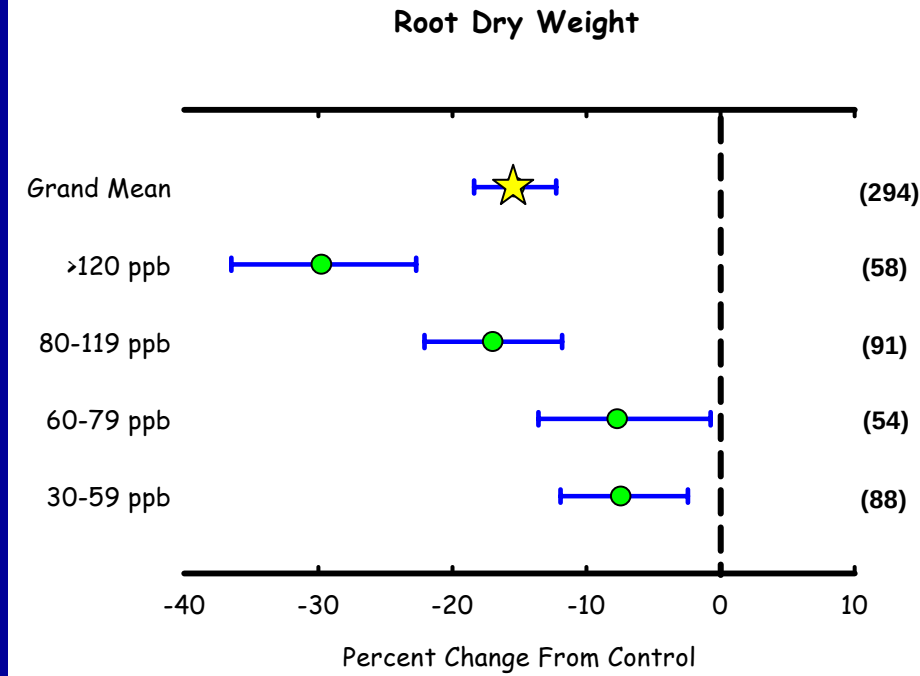
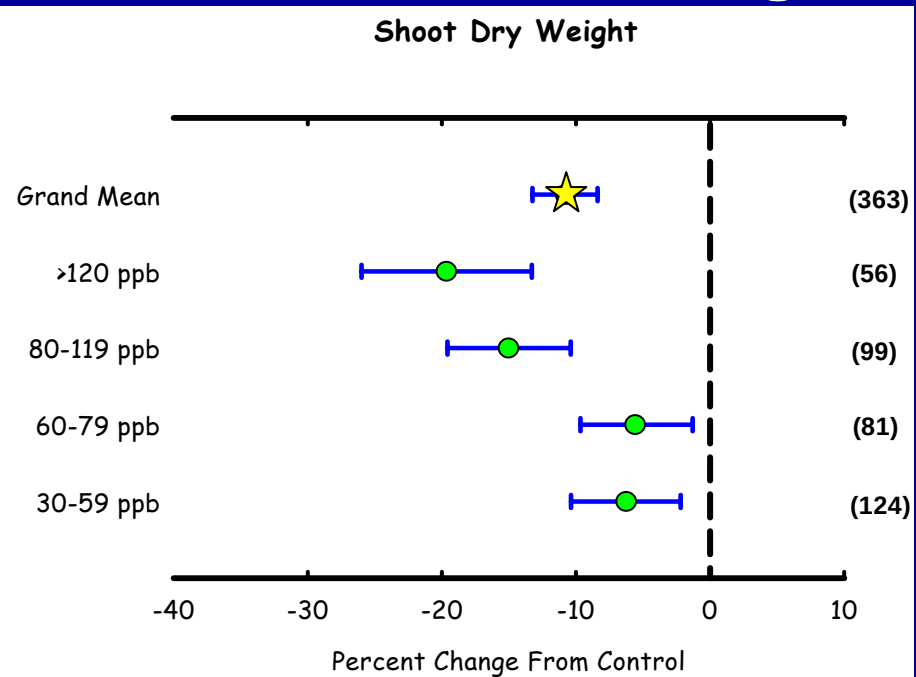
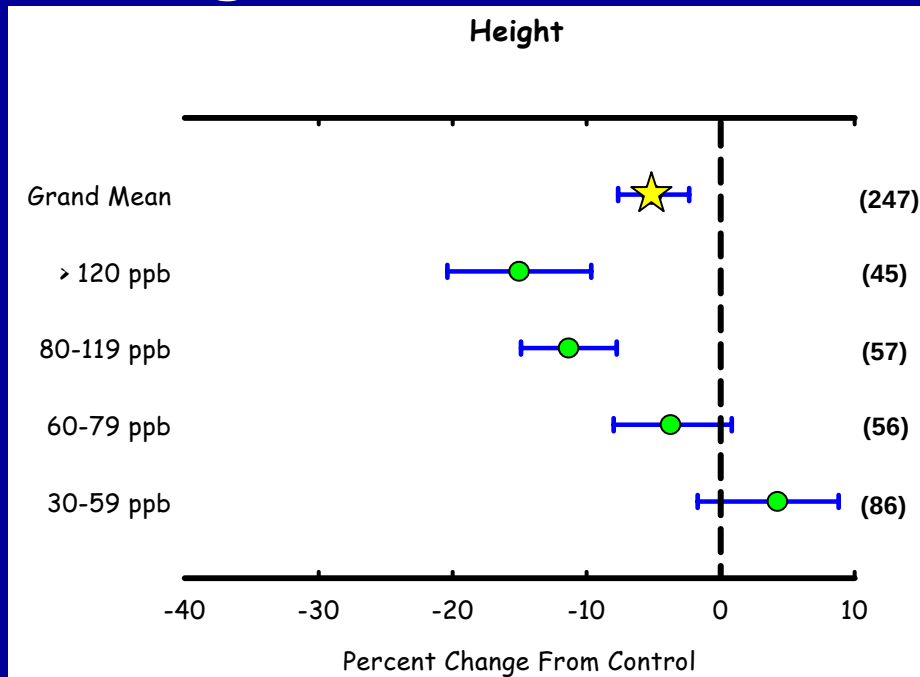




Consensus 2: Higher Ozone, greater loss.





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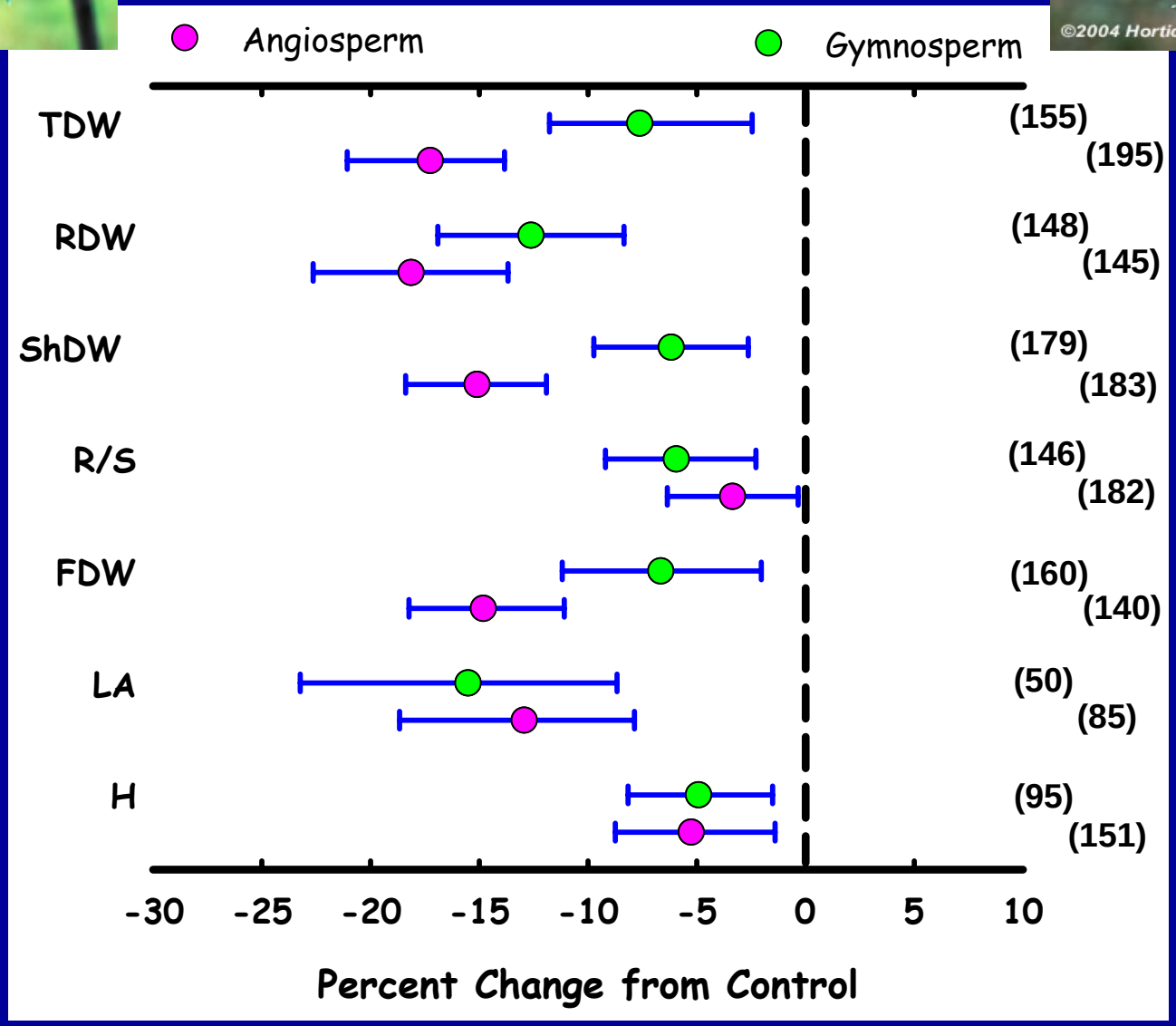
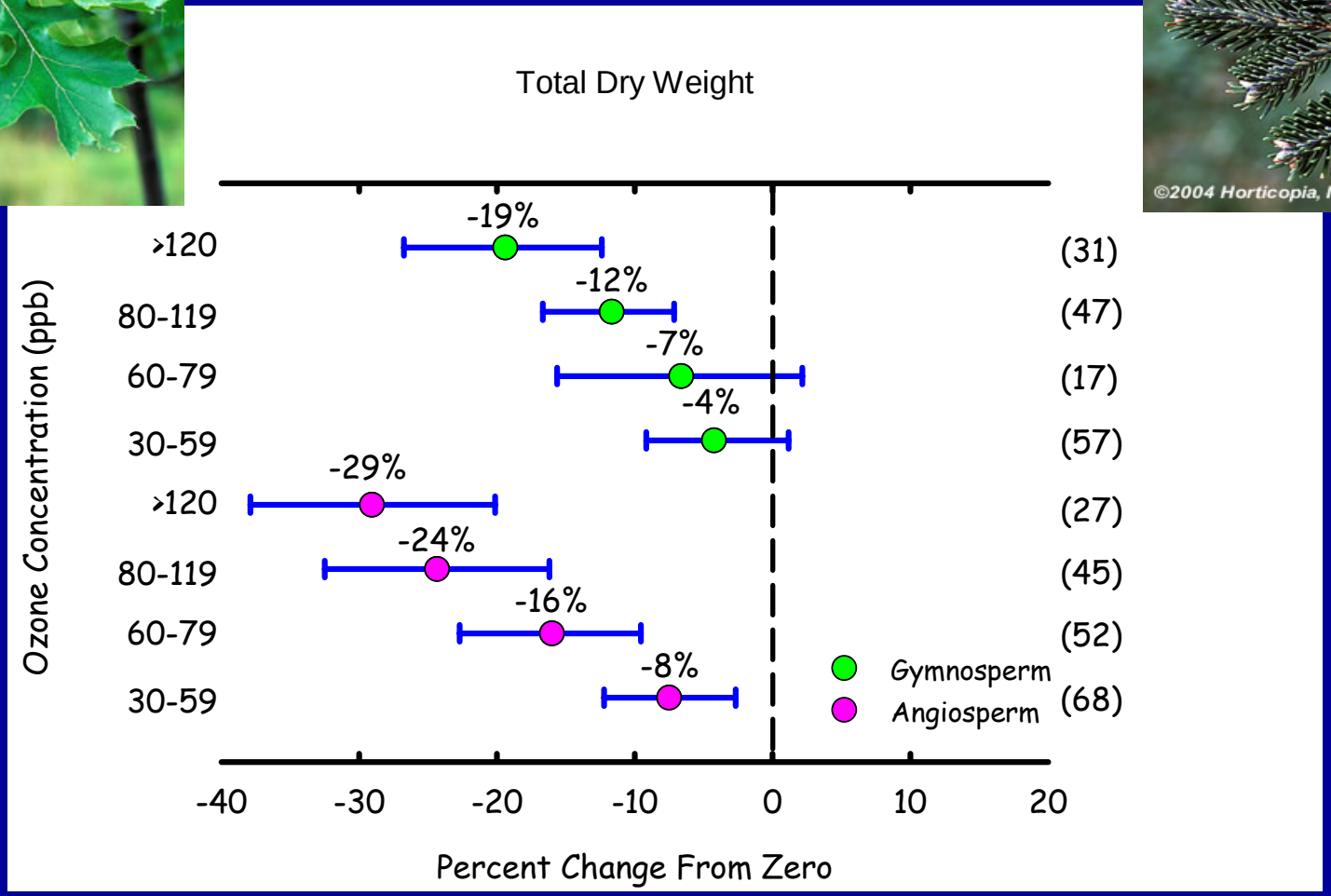
Functional Groups



Total Dry Weight: Categorized by Functional Groups and O_3



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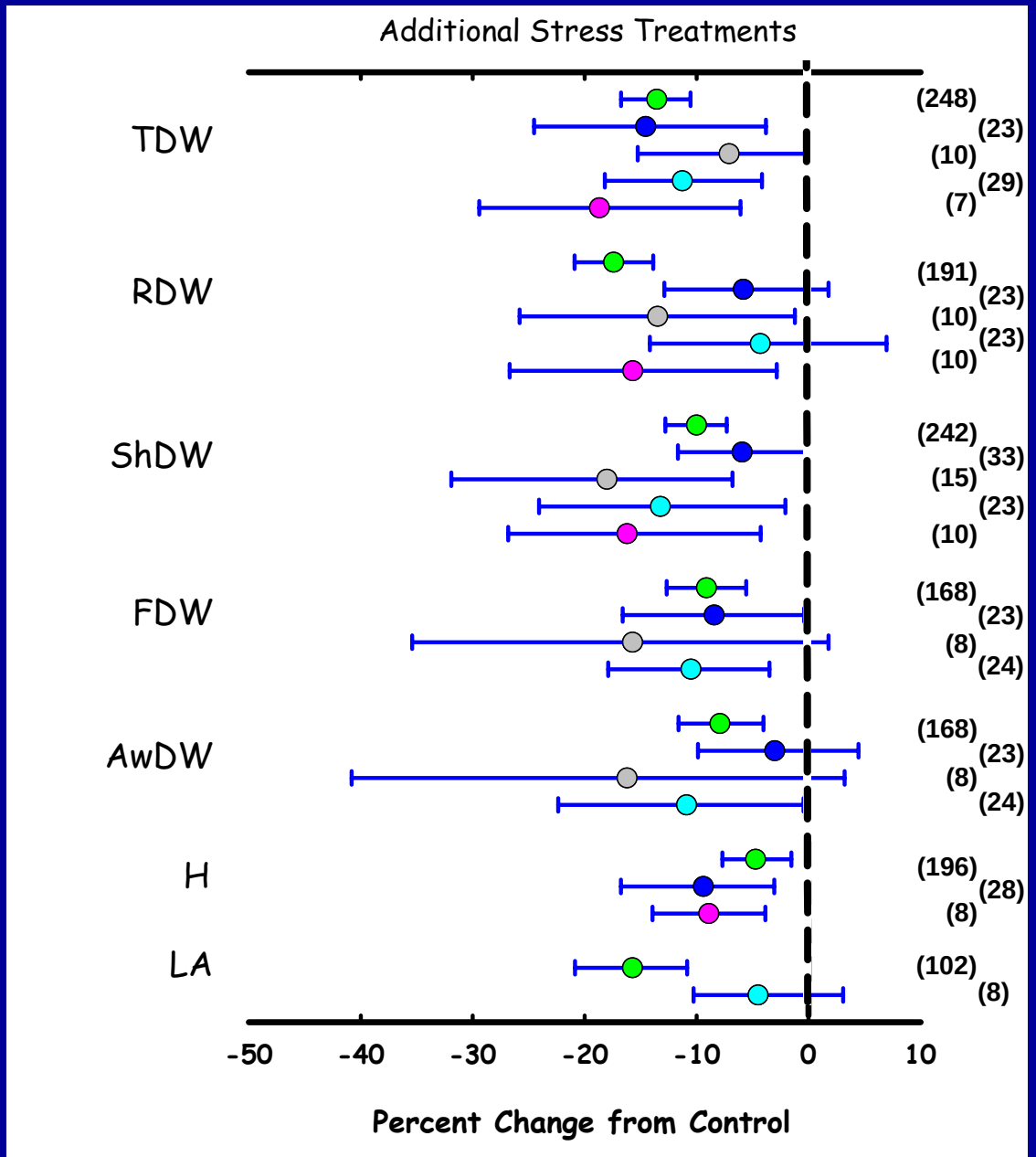
Consensus 4?



- No Additional Stress
- Acid Rain
- Drought
- Low Fertilizer
- Elevated CO_2

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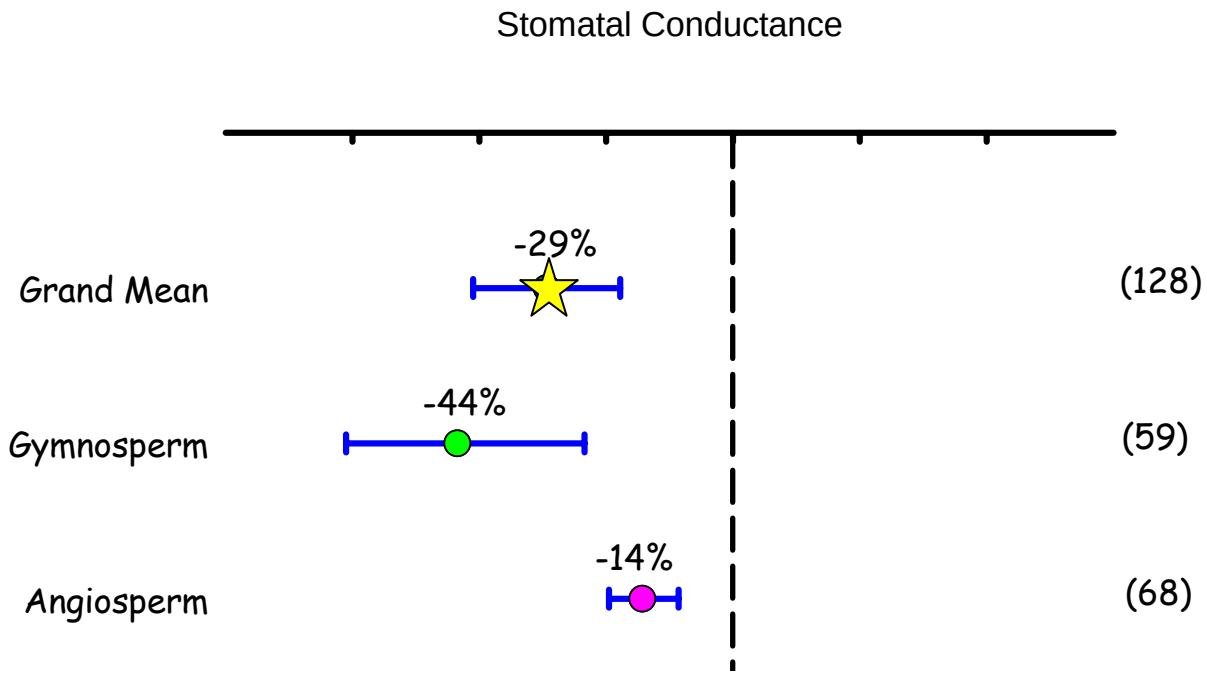
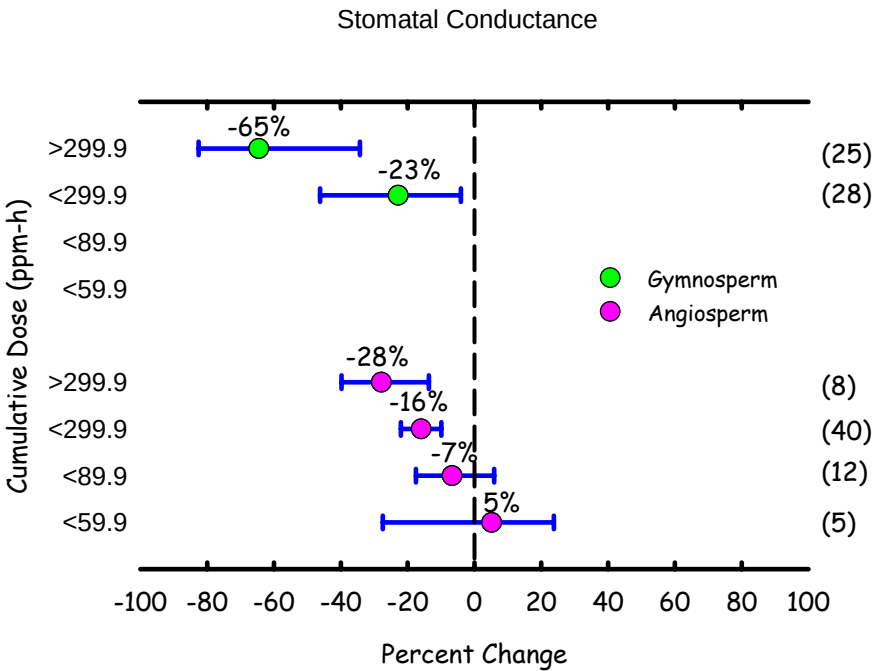
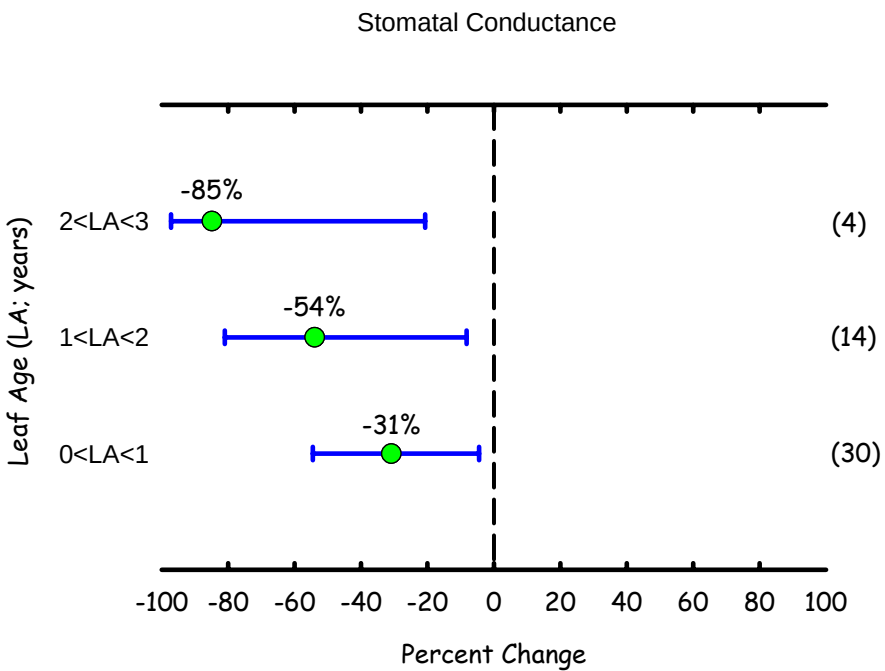
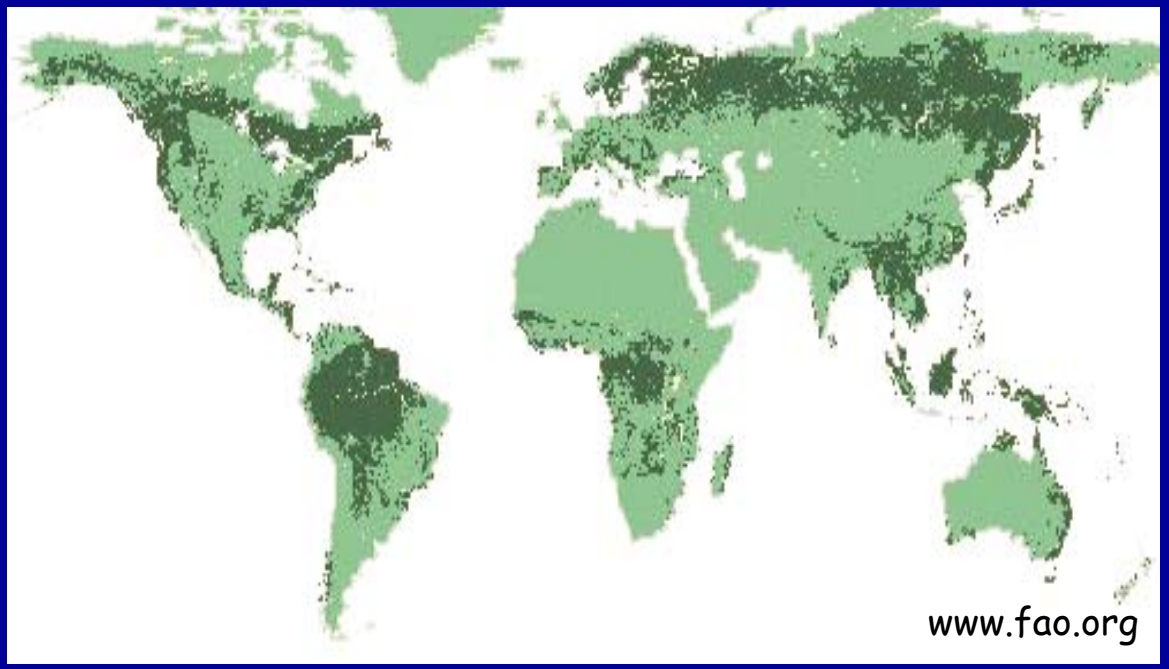

Stomatal Conductance
Grand Mean
-29%
(128)
Gymnosperm
-44%
(59)
Angiosperm
-14%
(68)


Stomatal Conductance
Cumulative Dose (ppm-h)
>299.9
<299.9
<89.9
<59.9
-65%
-23%
(25)
(28)
Gymnosperm
Angiosperm
-28%
-16%
-7%
5%
(8)
(40)
(12)
(5)
-100 -80 -60 -40 -20 0 20 40 60 80 100
Percent Change


Stomatal Conductance
Leaf Age (LA; years)
2<LA<3
1<LA<2
0<LA<1
-85%
-54%
-31%
(4)
(14)
(30)
-100 -80 -60 -40 -20 0 20 40 60 80 100
Percent Change

Global Forest Distribution



Reduced ability to mitigate increases in CO_2, leading to further warming.


APRIL 3, 2006
www.time.com AOL Keyword: TIME
SPECIAL REPORT GLOBAL WARMING
TIME
BE WORRIED. BE VERY WORRIED.
Climate change isn't some vague future problem—it's already damaging the planet at an alarming pace. Here's how it affects you, your kids and their kids as well
EARTH AT THE TIPPING POINT
HOW IT THREATENS YOUR HEALTH
HOW CHINA & INDIA CAN HELP SAVE THE WORLD—OR DESTROY IT
THE CLIMATE CRUSADERS

Thank You!

Funding:
Graduate Research for the Environment Fellowship (GREF)

Francis M. & Harlie M. Clarke Research Support Grant, UIUC

U. S. Department of Energy
Office of Biological and Environmental Research
Global Change Education Program

Advisor:
Steve Long

GREF Mentor:
Mac Post

Committee Members:
Atul Jain
Tom Phillips
Feng Sheng Hu

School of Integrative Biology
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Long Lab:
Joe Castro,
Charles Chen,
Frank Dohleman,
Emily Heaton &
Dr. Xinguang Zhu

Undergraduates:
Kasey Bryant
Katie Ciccodicola
Leslie Morrison
Janel Woods

Special Thanks:
Dr. Elizabeth A. Ainsworth,
Mihai Aldea,
Mark Harrison,
Dr. Pat B. Morgan